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DEVELOPMENT OF THE HUMAN INTESTINE AND ITS POSITION IN THE ADULT.*

BY FRANKLIN P. MALL, *Professor of Anatomy, Johns Hopkins University.*

Our knowledge of the early development of the human intestine is very complete, and at first thought it seems impossible to contribute anything new to it; yet, when we consider the topographical anatomy of the adult intestine, we are struck by the fact that there is dispute regarding the position of its various parts, and nothing is known about the development of its convolutions.

The aim in this study has been to follow the successive stages of the development of the human intestine, loop by loop, from the simplest form in the embryo to the adult. As a result, it has been found that the various loops of the adult intestine, as well as their position, are already marked in embryos of five weeks, and that the position of the convolutions in the adult is as definite as the convolutions of the brain.

The present study is closely associated with one recently published upon the development of the human cœlom, and the embryos here described were also published in part at that time.† In that paper the shifting of the viscera was emphasized in connection with the development of the cœlom, while in this paper only the convolutions of the intestine are considered.

The set of specimens in my possession is fairly complete, as all the important stages are represented. It is self-evident that a subject like this can be studied only by resorting to models, as a simple comparison of sections gives no opportunity to study the loops. A number of important stages were selected and modeled according to the method of Born. A list of these embryos is given in the accompanying table:

TABLE OF EMBRYOS MODELED.

No.	Length in mm. V. B.	Length in mm. N. B.	Diameter of Model.	From Whom Obtained.
XII	2.1	1.9	100.	Dr. Ellis, Elkton, Md.
II	3.	7.	67.	Dr. C. O. Miller, Baltimore.
IX	17.	14.	50.	Dr. Eyclesheimer, Chicago.
X	24.	20.	25.	Dr. W. S. Miller, Madison, Wis.
VI	24.		25.	Dr. C. O. Miller, Baltimore.
XLV	28.	19.	25.	Dr. Douglas, Nashville, Tenn.
XXXIV	80.	60.	10.	Dr. Ellis, Elkton, Md.
XLVIII	130.	110.	10.	Dr. Wilson, Worcester, Mass.

These models were then compared with one another, in order to follow the growth of the loops from stage to stage, using as guides the outline of the intestines in the sections and the blood-vessels, as well as the dissections of other embryos and those of the adult.

The loops which appeared to be homologous in the various models were next painted with the successive colors of the spectrum, beginning with the duodenum, and ending with the

*This paper has appeared in German in the Festschrift für Professor Wilhelm His zum 22. October, 1897, Archiv für Anatomie, Supplement-Band, 1897.

†Mall, Journal of Morphology, vols. 12 and 14.

cæcum. In this way, loops whose position were at first obscure, were finally found to have meaning. It is noteworthy that the successive stages in the development fit into one another accurately, showing that the first loops in the embryo are destined to form certain loops in the adult, and that this primary folding is in no way a haphazard process.

EARLY FORMATION OF THE ALIMENTARY CANAL.

The observations, upon the human embryo, of the first formation of the alimentary canal from the entoderm have now been extended to the very earliest stages.* In Graf Spee's embryo v. H. the entoderm lines the whole of the umbilical vesicle, and is in no way incorporated within the body of the future embryo. In fact, its plane is curved away from the entoderm, and is just the reverse of its direction in a later stage.

The next older stage is found in Graf Spee's embryo Gle, in which there is shown the beginning of the fore-gut. These two stages, given by Graf Spee, are the important ones to make our knowledge of the development of the alimentary canal complete, and from them we can easily follow through the successive stages until the adult form is reached.

After Graf Spee's embryo Gle, we have next to observe the constriction of the umbilical vesicle from the entoderm. The beginning of this constriction is already well marked in Kollmann's† embryo Bulle, my embyro No. XII,‡ and His's§ embryos SR and Lg. Unfortunately, we have no data regarding the extent of the alimentary canal in Kollmann's embryo Bulle, nor His's embryo SR. My embryo XII, however, is of about the same stage as the other two, and it has been cut into sections which are about perfect. The history of this embryo, as well as its cœlom, have been described by me recently, so I need not repeat them at this time.

EMBRYO No. XII. (2.1 mm. LONG).

The Figures 1 and 2, on Plate I, give the external form of the embryo, as well as the extent of the alimentary canal, which was taken from a reconstruction. The entoderm is already divided into fore-gut, mid-gut, and hind-gut. The fore-gut marks the pharynx, from which there are four diverticula on the dorsal side (Br′, Br″), one on the ventral side (T), and two near the mouth (M and S). These diverticula mark the first two branchial pouches, thyroid gland, mouth and Seessel's pocket respectively. At the junction of the pharynx and the umbilical vesicle there is a large diverticulum of the entoderm into the septum transversum, L, the beginning of the liver.

The hind-gut is a sharply defined cavity lodged in the tail of the embryo, communicating on the one hand with the allantois, All, and on the other with the neural tube by means of the neurenteric canal, N. C.

The attachment of the umbilical vesicle to the body indicates the extent of the mid-gut from which the future intestine is to arise. The cœlom is already beginning to be incorporated into the body to form the body cavity, and in the region of the liver and the omphalo-mesenteric vein the peritoneal cavities of the two sides of the embryo communicate freely, showing that at this early stage there is no complete ventral mesentery as has been described. This communication, marked O, gradually approaches the communication above the allantois, O′, and ultimately cuts off the umbilical vesicle altogether. A stage just before the umbilical vesicle

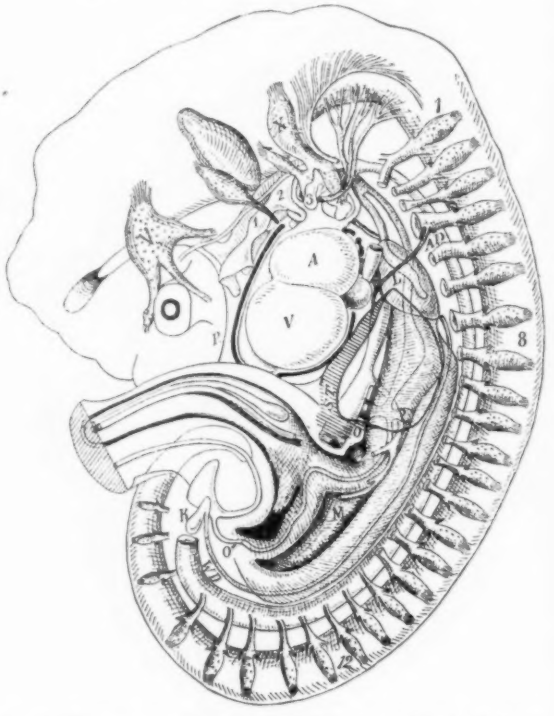

Fig. A.—Reconstruction of Embryo No. II. Enlarged 17 times. V and X, fifth and tenth cranial nerves; 1, 2, 3 and 4, cast of the branchial pockets; 1 and 8, first and eighth cervical nerves; 12, twelfth dorsal nerve; A, auricle; V, ventricle; L, lung; S, stomach; P, pancreas; WD, Wolffian duct; K, kidney; M, mesentery; ST, septum transversum; O, openings which communicate with the peritoneal cavity on the opposite side.

is completely separated from the embryo is represented in Fig. A, taken from embryo No. II.* By comparing Figs. 1 and A it will readily be seen that the spaces marked O and O′ in the two embryos are the same.

The intestinal canal of embryo II is given in Fig. 3. The drawing was made from the right side and gives the irregularity of the tube more accurately than my previous figures have done. The part between the liver duct and the cæcum, of course, marks the extent of the small intestine, and the part behind this, the large intestine. At this early stage, therefore, the cæcum is distinctly outlined. Attached to the small intestine there is this marked umbilical stem, but the vesicle no longer communicates with the intestinal canal. From the

* Graf Spee, His's Archiv, 1889 and 1896.
† Kollmann, His's Archiv, 1889 and 1891.
‡ Mall, Journal of Morphology, vol. 12, 1897, p. 417.
§ His, Anatomie mensch. Embryonen, 1885.

* Mall, Jour. of Morph., vol. 5; and vol. 12, p. 429.

umbilical stem there hangs down an extensive papilliform process which, from its appearance in section as well as its presence in younger embryos, shows that it is nothing more than an island of vessels and villi from the umbilical vesicle. These seem always to be incorporated within the body at this point and degenerate later on.

Thus far it is very easy to follow the formation of the intestine, when the embryos already described by His are also taken into consideration. My embryos, Nos. XII and II, are from the end of the second and fourth weeks respectively, so it takes about two weeks for the intestine to become outlined after the entoderm is incorporated within the body of the embryo. The intermediate stages have all been described by His in his great monograph. In his Atlas the external form of embryos intermediate to XII and II is given, and in the text the alimentary canal of embryos Lg, BB, Lr and R is again pictured in woodcuts. They all show the gradual constriction of the stem of the umbilical vesicle to form the intestinal tube between it and the liver.

As the umbilical vesicle is being separated from the intestine, all of the viscera are moving from the anterior end of the embryo towards its tail. This is also the case with the diaphragm and the origin of the cœliac axis and the superior mesenteric arteries from the aorta.* A comparison of figures A and 1 shows that the whole stem of the umbilical vesicle in embryo XII must have moved toward the tail through the space of at least ten body segments to have gained the position it holds in embryo II.

At the same time that the intestine is bending towards the ventral median line the loop is also beginning to turn upon itself, so that the aboral end moves towards the left side, and the oral end to the right of the body. This process is already beginning in embryo II, Fig. 3, but rapidly becomes more marked, as is beautifully shown by the His embryos and their models made by Ziegler. By this process the loop is separated into right and left halves, the left half to form the large intestine, and the right half, the small intestine. In a short time, however, as the loop grows longer and longer, not all of the left half is occupied by the large intestine, as the cæcum is now no longer in the middle of the loop.

EXTENSION OF THE LOOP INTO THE CORD.

As the loop of intestine enlarges it extends immediately into the umbilical cord, as was first shown by Meckel† for the human embryo. To what extent this is common to the mammals is not known, but my experience is that it is frequently found in other mammals, and from the examination of many pigs' embryos I can state that in them a portion of the intestine always extends into the cord.

Figures 4, 5 and B are from embryo IX, a specimen about five weeks old. The intestine extends into the cord as a single loop, with the plane of its mesentery horizontal to the long axis of the body. In general its arrangement is much like that of His's embryos S$_1$, Sch*, KO† and RM‡. It is noticed in the figures that the large intestine lies altogether within the sagittal plane of the body, a position it retains until the intestine is returned to the peritoneal cavity proper. The right half of the loop has a number of small bends in it, which are of great importance in the further development of the intestine. I have marked them with the numbers 1, 2, 3, 4, 5 and 6 in order to follow them with greater ease in the drawings of older embryos.

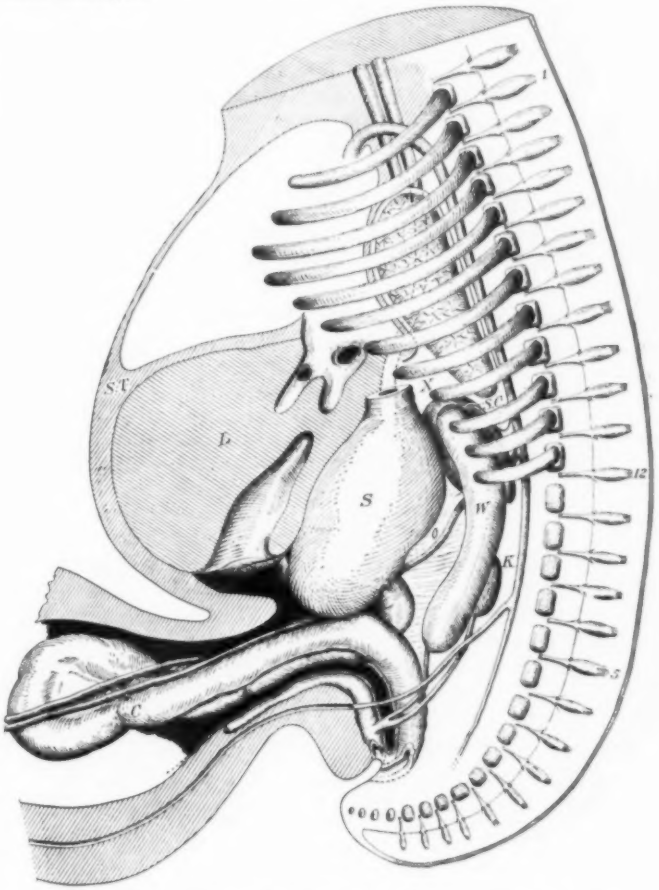

FIG. B.—Reconstruction of Embryo No. IX. Enlarged 20 times. ST, septum transversum; L, liver; S, stomach; C, cæcum; W, Wolffian body; K, kidney; 1 to 12, dorsal ganglia; O, omphalo-mesenteric artery; SC, suprarenal capsule; X, communication between pleural and peritoneal cavities.

In the middle of the mesentery of the loop and in the median line lie the omphalo-mesenteric vein and artery. At the point where these vessels cross the intestine, Fig. 4, u, we have a landmark which is of use in comparing the intestine of this embryo with that of older embryos. The point of communication between the umbilical vesicle and the intestine also represents the position of the persistent Meckel's diverti-

* Mall, Jour. of Morph., vol. 12, pp. 441 and 442.
† Meckel, Meckel's Archiv, 1817.

* His, A. m. E., III, p. 19.
† His, Abhandl. d. sach. Gesch., XIV, Taf. II, Fig. 3.
‡ His, ibid. XV, p. 677.

culum. If the adult intestine is about six meters long, and if the distance from the cæcum and Meckel's diverticulum is about one meter, then the length of the intestine between the omphalo-mesenteric vessels and the cæcum is about one-sixth of the whole intestine. In both embryos IX and X, as well as in His's embryos S_1 and Sch, the extreme bend of the intestine (Fig. 4, u) marks one-sixth the distance from the cæcum to the duodenum.

The blood-vessels to this whole loop within the umbilical cord arise from the omphalo-mesenteric or the future superior mesenteric artery. When this is compared with the arterial supply in the adult intestine it is again found to correspond. In this early stage the omphalo-mesenteric artery supplies the same portions of the intestine that the superior mesenteric artery does in the adult. Not only by the form of the large intestine, but also by its blood supply can we divide it into two portions, that portion which is at right angles to the body, supplied by the superior mesenteric artery, and that parallel with the body and supplied by the inferior mesenteric artery.

The relation of the intestine and liver to the body of the embryo is given in Fig. B.

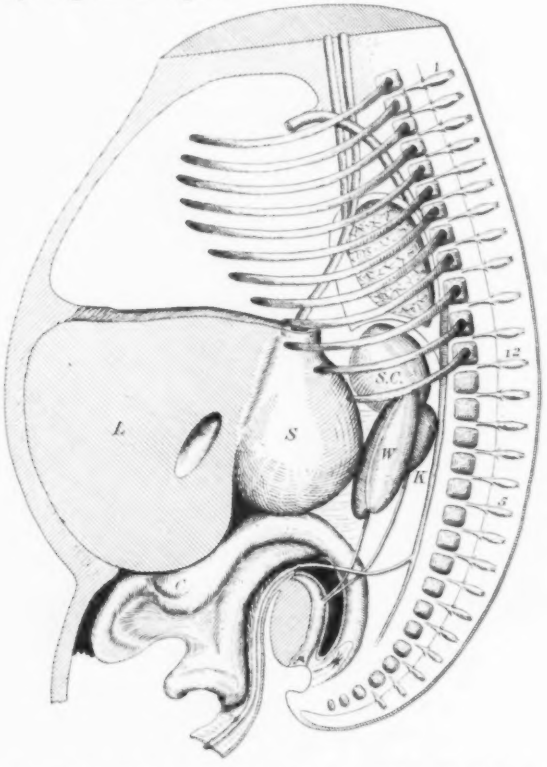

FIG. C.—Reconstruction of Embryo No. X. Enlarged 8 times. 1 to 12, dorsal ganglia; SC, suprarenal capsule; W, Wolffian body; K, kidney; L, liver; S, stomach; C, cæcum.

BEGINNING OF THE CONVOLUTIONS.

A stage somewhat older than the one just described is given in Figures 6, 7 and C. In comparing Figures B and C it is seen that the liver has descended decidedly; it has moved away from the head to the extent of at least three segments. While in embryo IX the septum transversum is opposite the eighth dorsal nerve, and the lower edge of the liver opposite the first lumbar nerve, in embryo X the septum is opposite the eleventh dorsal, and the lower edge of the liver opposite the second sacral nerve. In other words, the septum has descended three segments and the lower edge of the liver six segments. Not only has the liver descended through its absolute growth, but the whole organ has descended also. This movement has had a marked effect upon the form of the large intestine, and the direction of the intestine in general, as the figures will readily show.

While this movement is taking place the convolutions are also becoming more and more distinct. Every loop as outlined in embryo IX is more marked in embryo X. In general, the twisting has become more pronounced as the cæcum is approached. The loops 1, 2 and 3 are only slightly more bent in X than in IX, while the loops 4, 5 and 6 have become much more sharply defined. In general, the length of the loops has doubled itself while the diameter of the intestine increased but one-third.

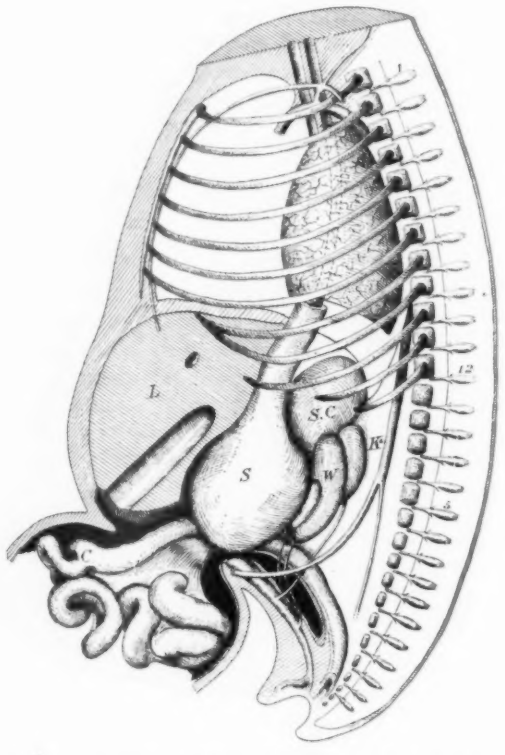

FIG. D.—Reconstruction of Embryo No. VI. Enlarged 8 times. S, stomach; SC, suprarenal capsule; C, cæcum; K, kidney; W, Wolffian body.

The next embryo (VI) I have modeled is only slightly larger than No. X. I give the same views for this embryo as I gave for Nos. IX and X. Fig. D compared with Fig. C gives the general relation of the intestine to the body. The large intestine has not changed its position much; it has

elongated, but has not increased its diameter. There is now added to the cæcum a marked vermiform appendix. The stomach has descended more than before, the great omentum forming a sac and extending well over the large intestine.

A comparison of Figs. 6 and 7 with Figs. 8 and 9 shows the growth of the small intestine. The duodenum is still bulged at its stomach end and only the lower portion of it is as small as the rest of the intestine. This enlarged duodenum is so decided that, at first sight, one might think it belongs to the stomach, but since the liver and pancreatic ducts open into it in all the specimens, there is no doubt but that it belongs to the intestine. Of course there is the possibility of these ducts shifting, but this seems to me very improbable.

The second portion of the intestine, 2, is now curved towards the dorsal side of the embryo, and, as in embryo X, this is also the case with its mesenteric attachment. We are all familiar with this portion of the intestine in section, as it has this hooked mesentery showing that the intestine has bent backward. The next portion, 3, is bent upon itself to such an extent that it rolls around on the dorsal side of the omphalo-mesenteric artery, to project to the left side of the clump, as shown in Fig. 8. It also has the hooked mesentery in section, as the mesentery is very much bent upon itself.

It has been customary for embryologists in discussing sections of the intestine with me to call this portion of the intestine the duodenum, on account of its position, as well as for its very characteristic mesentery. At first I was strongly inclined towards this view, but more mature consideration of models convinced me that both the loops 2 and 3 are finally transferred to the left side of the body to form the upper part of the jejunum.

The fourth portion of the intestine, Fig. 8, 4, has its beginning in the earlier embryo on the left side of the mesentery as shown in Fig. 6. It is readily seen by the comparison of the two figures that the loop 4, in Fig. 8, is only an exaggeration of the same in Fig. 6. While this loop begins on the left side it ends on the right. In all the figures the extreme bend of the loop 4 is marked a, and a comparison of the figures will readily show that this is always the homologous loop.

Following the loop 4 there is the loop 5, which is altogether on the right side in embryo X, Fig. 6, and about equally distributed on both sides in embryo VI. In both Figs. 6 and 8 the end of the loop 5, b, approaches the loop 3, and this relation is also present in Fig. 10. In the figures this point is marked b, and the similarity of this loop in them is very apparent. Loops b and 3 are just touching in Fig. 6, while in Fig. 8, through the elaboration of loop 4 and its gliding to the right side of the mesentery, the loop 5 has been brought nearly in contact with loop 3. At any rate the relations of loops 5 and 6 to the umbilical vein in both figures show that the numbering of the two loops is not far amiss.

The loop b in Figs. 4, 6, 8 and 10 holds the same relation to the cæcum and umbilical vessels in all four embryos. This point seems to be the fixed point for the loop on the right side of the mesentery as the point marked a is for the left. Between b and the cæcum the intestine is thinner and the loops are smaller than in the upper part of the intestine. For this reason as well as for the fact that there is no sharp landmark other than the umbilical vessels between loop b and the cæcum, I have classed this whole region as one group and marked it with the single number 6.

The convolutions in embryo XLV, Figs. 10 and 11, are only an exaggeration of those of embryo VI. The loops 1, 2 and 3 are much the same as before. The loop 1 is again defined by the extent of the head of the pancreas. The loops 2 and 3 together are now S-shaped instead of a simple curve as in embryo VI. My interpretation of this is that the loop 3 is held in place by the opening of the umbilical cord, as at this point the intestine leaves the body, while the loop 2 is beginning to rotate to the left side of the body with the rest of the intestine. The loop 4 on the right side has enlarged, however, and has pushed its way in between the loops 3 and 5. On the left side the loop 4 has made for itself another twist, so it now appears as several loops. The loop 5 is much as it was before, only it has increased its length somewhat. It is easy to see the loop 6 of embryo VI converted into that of embryo XLV by imagining x in Fig. 9 to be drawn over to the opposite side to form x in Fig. 10. In so doing x′ and x″ remain back to form the loops marked the same in Fig. 11. In addition to this the loop y in Fig. 9 has become bent over to the left side to form y in Fig. 11.

All these twists and curves in the small intestines of the four embryos just described can be followed fairly well in the figures, and the reader may think that there is considerable imagination required to do this. Any one, however, who may study the models in which the corresponding loops have been marked as in the figures will not doubt regarding the accuracy of this description. It is a most remarkable fact that four specimens should correspond as well as they do here. Were the whole affair more or less haphazard no comparison whatever could have been made.

ROTATION OF THE SMALL INTESTINE.

A comparison of embryos II, IX, X, VI, His's Pr and KO, shows that the change in position of the intestine and its future twisting is due to the descent of the abdominal viscera, accompanied by the relatively rapid growth of the small intestine. The following table gives the measurements of the intestines in these embryos as well as the level of the stomach and the cæcum. The measurements of the intestine of embryos Pr* and KO† have been taken from the illustrations given by His and are only approximations. The position of the stomach here given is its lowest measurements including the omental bag.

TABLE GIVING THE POSITION AND LENGTH OF THE SMALL INTESTINE.

Number of Embryo.	Position of Stomach.	Position of Cæcum.	Length of Intestine.	
			Small.	Large.
II	1 Dorsal	9 Dorsal	1.7 mm.	1.5 mm.
Pr	5 "	10 "	3.	1.5
KO	8 "	12 "	4.	3.
IX	3 Lumbar	5 Lumbar	9.	3.7
X	5 Lumbar	3 Sacral	19.	7.
VI	1 Sacral	1 Sacral	34.	8.
XLV			52.	8.

* His, Atlas, Theil III, Taf. 1, Fig. 4.

† His, Abhandl. d. K. S. Ges. d. Wiss., 1888, Bel. XIV, No. 7.

A study of this table by comparing it with the illustrations shows that the intestine is gradually elongating and at the same time being pushed towards the pelvis by the large liver and other organs descending upon it. In No. II the intestinal canal is still a comparatively straight tube, but in Pr and KO it is already well bent, is much larger than in No. II and is pushed into the cord. In No. IX it is located in the cord. From No. II to No. IX the small intestine has increased its length five times and the large intestine over two times, and the space which they should occupy within the body has remained the same. Under these conditions the intestine must escape if it has a chance, and the cœlomic space within this cord naturally receives it. This movement of the intestine is due to mechanical causes and, were the cœlom of the cord not there to receive it, the intestine no doubt would make room for itself within the body. I do not think that the umbilical ducts had anything to do with it any more than to keep the opening in the cord open, for, before the intestine begins to enter the cord, its connection with the duct is severed.

After the intestine has entered the cord, No. IX, Fig. B, the small intestine grows rapidly, as the table and Figs. C and D show. Embryos IX, X and VI are all about the same size, but no doubt VI is considerably older than IX; the organs are all firmer and more developed, and the small intestine has increased its length considerably more than the large intestine. The organs have all been pressed down to the pelvis as far as they will go, as Fig. D. shows. In so doing the large intestine makes a sharp bend in the neighborhood of the fourth lumbar segment, in all of the embryos given in the above table. This bend, therefore, may be looked upon as a fixed point toward which the viscera descend, but beyond which they do not go. Of course after the intestine is in the cord the loops may descend lower, but within the body this is a very fixed point.

After the intestine is within the cord its further elongation and its mesenteric attachment causes it to be thrown into coils, as shown in the plates. The large intestine lies, however, in the sagittal plane of the body, partly within the body and partly within the cord. It does not grow as rapidly as the small intestine; and, as the small intestine is folded into coils, the whole begins to rotate around an axis which is identical with that of the large intestine. By this process the small intestine is gradually turned from the right to the left side of the body, and in so doing is rolled under the superior mesenteric artery. This takes place while the large intestine has an antero-posterior direction and before there is any transverse colon. This latter is the result of a kinking which is to follow, and is in no way formed by a shoving of the large intestine over the small, as given in the Hertwig diagrams.

RETURN OF THE INTESTINE TO THE PERITONEAL CAVITY.

Although it is comparatively easy to understand how the intestine leaves the peritoneal cavity to enter the cord, it is extremely difficult to see how and why it returns. When the intestine enters the cord the communication of cœlom with the body cavity is very free and the intestine is small, but when the intestine returns to the body cavity the intestine is large, while the opening is small, Fig. D.

In embryo No. II, and in younger embryos, the belly stalk is very large and contains within it no muscles nor permanent blood-vessels of the abdominal walls of the future individual. It is not until the muscles wander, carrying with them their nerves and to a certain extent their blood-vessels, that the belly wall is finally completed.* In embryo No. VI, for instance, the rectus abdominis is about half-way around from the dorsal to the ventral median line, thus leaving a large area between the two recti, which is little more than a membrane. It seems that, until the abdominal walls are fairly completed, the intestine remains within the cord, and, at the last moment before the two recti come together in the middle line, the intestine returns to the peritoneal cavity.

In very young pigs' embryos, when the mammary ridge is still over the muscle plates, I have found that the segmental arteries form an anastomosis with one another throughout the extent of this ridge. This artery goes through a series of muscles which have just been split off from the muscle plates. As the embryos grow, the mammary ridge wanders towards the ventral median line† and carries with it this anastomosis of segmental arteries and the portion of muscle plates which are destined to form respectively the internal mammary, deep epigastric arteries and the rectus abdominis muscles. The nerve connections of the various segments of the rectus are formed as the muscle is splitting off from the muscle plates, and in this way the origin of the different parts of the rectus is indicated, as already shown by Nussbaum. What I have here described for the pig can also be verified for the human embryo, and this will make it plain how the lateral body walls are formed from the belly stalk.

But the closing off also takes place from above downwards. In an early stage, while the septum transversum is still in the neck, the umbilical vesicle also extends upwards. The heart is first closed off by the beginning of the membrana reuniens, and the ventral wall is completed by the amnion moving over the embryo from left to right.‡ Then the umbilical vesicle is pinched off from above downwards, corresponding with the descent of the liver and other viscera. In embryo II the stalk extends from opposite the third dorsal vertebra to opposite the second sacral, while in embryo IX it extends from opposite the second lumbar segment to opposite the fourth sacral. In other words, the oral end of the stalk has receded eleven segments, and its aboral end two segments; or the whole stalk is moving away from the head, and its attachment to the body is rapidly becoming smaller and smaller. Later the growth of the abdominal walls is greater between the cord and the pelvis, as shown by the sections made by Merkel.§

At one time I thought of the possibility of the expansion of the cœlom of the cord and its incorporation with the abdominal cavity, and this was also carefully investigated. Were this

* See also Nussbaum, Verhandl. d. anat. Ges., 1894, '95 and '96.

† O. Schultze, Anat. Anz., Bd. 7; and Verhandl. d. phys. med. Ges. Würzburg, Bd. 26.

‡ Mall, Journal of Morphology, vol. XII.

§ Merkel, Abhandl. d. k. Ges. d. Wiss. in Göttingen, Bd. 40.

the case it would be necessary to find stages in which the rectus abdominis had wandered up into the stalk to incorporate it and to enclose the intestine within it. No such stage has ever been found, while on the contrary the recti nearly close the communication between the stalk and peritoneal cavities, before the intestine slides back into the body.

The return of the intestine into the body must take place very rapidly, for I have never seen a specimen in which it is in the process of returning. Embryos 40 mm. long either have the intestine in the cord or in the peritoneal cavity, and, if it is in the latter, the communication between the cord and peritoneal cavity is open and surrounded by a thin membrane, showing that it also is being closed. This membrane now closes the whole opening, and later the recti muscles wander into it to complete the abdominal walls.

Since I was unable to find the desired stage in the human embryo, I examined a number of pigs' embryos, hoping in this way to find stages in which the intestine is returning to the peritoneal cavity.

In a pig's embryo 12 mm. long a single loop of intestine extends into the extra-embryonic cœlom, beyond the cord and on the right side of the body. It is still in communication with the umbilical vesicle, which, in turn, is attached to the ventral body wall over the heart. As the loops of the intestine increase in number in older embryos, they make room for themselves below the liver and in front of the Wolffian body, for, unlike the human embryo, there is considerable space in this region. In general the greater number of loops remain within the body cavity of the embryo, and the loops within the cord are not numerous. The increase of loops within the body cavity and their rotation seem to draw upon the loops within the cord, so that when the embryo has reached 35 mm. in length, the loops have all returned to the body cavity.

No doubt, in the human embryo some similar mechanism is present in the return of the loops to the peritoneal cavity, but, as the critical stage has not yet presented itself, this question must be left open for future observation.

POSITION OF LOOPS AFTER THE INTESTINE HAS RETURNED TO THE PERITONEAL CAVITY.

Although it is extremely difficult to understand how the intestine returns to the peritoneal cavity, it is not difficult to recognize the various loops after their return. Unfortunately I have not been able to study carefully a good stage between embryos XLV and XXXIV, as the various specimens of this stage at my disposal were not perfect, or if so, the series of sections were broken. It was not until a number of good specimens had been spoiled for this present purpose that I found that, by removing the ventral abdominal walls, good series could be obtained. If this is not done, the intestine is very liable to be imbedded poorly, and as a result the sections are not perfect. Dissected specimens, on the other hand, cannot be relied upon, for, when once handled, it is impossible to replace the intestines to their original position with certainty, unless they have been modeled as soon as the abdominal walls were removed. Of course dissection is an extremely good method of control, but for a comparison of the loops I think that no method will improve the model. Then it was found that all the loops represented in No. XLV are again recognizable in XXXIV, and on this account it is believed that an intermediate stage is unnecessary, unless that stage is one in which the intestine is in process of returning from the cord to the peritoneal cavity.

A comparison of Figs. 10 and 12 shows that the loops of XLV are again represented in XXXIV. The marked change is that the mesentery of the large intestine has increased greatly. The loops of the upper part of the intestine have rolled completely to the left of the superior mesenteric artery, and the loops which were formerly within the cord have now been transferred *in toto* to the right side of the body. While this has been taking place the stomach has been enlarging also, and by the tilting of the intestine the pyloric portion of the stomach, d, has come nearer the cæcum, about to the point marked d' in Fig. 10.

This shifting of the loops, half to the right and half to the left side, as well as the sliding down of the stomach towards the cæcum, has finally locked the duodenum (loop 1) around the root of the mesentery, as shown in Figs. 12 and 13. As the loops come out on the left side, Fig. 12, we have the beginning of the second group of loops (2) of the intestine. The deeper layer of these loops, not shown in the figures, is a single curve lying immediately in front of the mesocolon. The loops 3 together can easily be imagined as arising from the same as in Fig. 10 by a simple bending of the portion on the dorsal side of the large intestine towards the ventral median line. The loop 3 which lay formerly on the right side of the body is now altogether on the left side. In the illustration, with the exception of its ending in loop 4, it cannot be recognized as the loop 3 of Figs. 10 and 11. In the models, however, the loop 3 forms a distinct cluster situated between the loops 2 and 4, and therefore, by exclusion, it must represent the loop 3 of embryo XLV.

The similarity of the loop 4 in embryos XLV and XXXIV is very striking. Its beginning, the arrangement of convolutions and their position are much the same in both embryos, if the change in position of the intestine in the older embryo is taken into consideration. The next cluster I have marked 5, and the remaining portion 6. The loops 6 are again smaller, and their diameter is less than those of the upper part of the intestine.

In this embryo we can see pretty well the adult form of the intestine, only that the mesentery is transverse to the body rather than diagonally downward toward the right side. In this embryo we also see the relation of the intestine to the mesentery better than in the adult. At this time the mesentery is relatively simple, as but few secondary adhesions have taken place. Unraveling this stage into the one represented by embryo XLV, we can fully understand the relation of the mesentery to the abdominal viscera. These two stages represent beautifully the arrangement of the intestine in the dog and monkey respectively.

The following table gives the length of the various loops of intestine in the embryos described. The measurement was taken along the distal border of the intestine and therefore is considerably longer than along the mesenteric border. But this is a border easily measured, and the length of the hard-

ened intestine is considerably less than where it is taken out fresh and stretched. The table shows that the lower end of the intestine grows more rapidly than the upper end until the intestine is returned to the peritoneal cavity, when the upper end of the intestine grows more rapidly.

LENGTH IN MILLIMETERS OF THE DIFFERENT PORTIONS OF THE INTESTINE IN THE DIFFERENT EMBRYOS STUDIED.

No. of Embryo.	Small Intestine.						Large Intestine.	Total Length.	
	1	2	3	4	5	6		Small Intestine.	Whole Intestine.
II	—	—	—	—	—	—	1.5	1.7	3.2
IX	1.6	1.2	1.2	1.3	1.4	2.4	3.7	9.1	12.8
X	2.	2.6	2.6	3.6	2.4	5.8	7.	19.	26.
VI	1.8	2.9	3.8	7.4	7.2	10.8	8.	33.9	41.9
XLV	3.6	3.2	5.6	13.2	9.2	17.3	8.	52.	60.
XXXIV	11.	39.	50.	89.	67.	110.	50.	366.	416.
XLVIII	22.	62.	70.	150.	95.	175.	86.	474.	560.
Infant[1]	—	—	—	—	—	—	570.	2100.	—
Adult[2]	—	—	—	—	—	—	—	5372.	—

[1]After Weinberg. [2]After Sernoff.

It is not difficult to follow the development of the intestine from embryo XXXIV to the adult, by simple dissection; but, in order to be more certain of the relation of the deeper layers of the intestine of an older embryo, I had the intestine of a four months' fœtus modeled. In this, however, the mesentery was not included, as the loops only were desired. The intestine was removed from the body *in toto*, and carefully imbedded in paraffin, after which it was cut into sections 100 μ thick. These were drawn upon wax plates, at a scale of ten, thus making each plate one millimeter thick. The intestine outlines were then cut out, and the remaining frame-work of wax plates was carefully piled, and the cavities cast with plaster of Paris. After the plaster had set, the wax was melted in hot water, leaving the plaster cast of the intestines enlarged ten times.

Figs. 14 and 15 are drawings of this model, and they show about what would be expected in a stage more advanced than embryo XXXIV. The large intestine has become more extensive, the transverse colon having become bent forward, and the descending colon having a very marked S in it before it passes over to the rectum. The intestines, as a whole, are shifted more to the left side of the body, so that the colon encircles the intestine rather than simply marks its border. The lower part of the small intestine is filled with a great quantity of meconium at this stage, showing that vermicular action must take place at this early time, as all this substance has been propelled downward to the cæcum. This same condition I have noticed in other embryos of the same stage.

The loops have shifted somewhat over one another, but one could not unwittingly separate the model so that it would not fall into its respective groups. This separation is given in Fig. 15.

It is evident that the loops are now shifting and adjusting themselves to the space they have to occupy. The loops 2 and 3 are still recognizable, while the loop 4 has been pushed back of them and extends over about as great an area as loop 6. The loop 5 lies about in the middle line, is more to the left than in the younger specimens, and is destined, ultimately, to lie in the left iliac fossa. The loop 6 will descend into the pelvis when the pelvis becomes large enough to hold it, making room for the green, which is shifted to the right side and to the umbilical region. All this will be accomplished with the descent of the cæcum to form the ascending colon, thus bringing about the re-arrangement of the position of the loops by a rotation of the lower end of the intestine toward the pelvis.

POSITION OF THE INTESTINE AFTER BIRTH AND IN THE ADULT.

It is relatively easy to follow the intestines in an older fœtus or in a new-born child after they have been hardened in formalin or other substances which keep the intestines sufficiently in place while they are being handled. I have examined the intestines by this method in a number of new-born children, and have found them much the same as in fœtus XXXIV and XLVIII. The intestine passes over and back along its mesenteric attachment from left to right, while in fœtus XXXIV and XLVIII, the direction of the mesentery of the intestine is at right angles to the axis of the body, in the new-born this attachment is from the left hypochondriac region diagonally downward towards the right iliac fossa, with a curve somewhat towards the right fossa. This makes its course a curved line, which is also curved spirally around the body. While above it is left and deep, below it is right and superficial. The intestine now is attached along this line, crossing and recrossing it, over and back again from duodenum to cæcum. In so doing, the convolutions above lie to the left of the mesentery, and are piled upon one another, making the planes of their circles at right angles to the body, while below and to the right they lie in front of the mesentery, and the planes of the convolutions are perpendicular to the body.

For the adult I have examined the intestines of about 50 cadavers, in which 41 were not diseased nor adherent in any way. Of them, one-half were negroes. The intestines were all coagulated in position, the cadaver being on its back, with about 1.5 to 2 kilos of pure carbolic acid. It was injected in 33 per cent. solution to preserve the subjects for dissection. After the abdominal cavity was opened the position of the intestines was either sketched or photographed and then the intestines removed, loop by loop, making a tracing of their course at the same time. In this way the general course of the intestine was followed. In removing the loops it was found that in nearly all specimens they came out as distinct groups, as for instance the group on the right side of the body was usually one loop crossing the middle line but twice; once to communicate with the loops above, and once with those below. To follow the intestine in this way the method was amply sufficient, but free-hand modeling or corrosion gives a much more satisfactory result. The models of three specimens which I have made in this way have proved to be of great value in gaining a clear idea of the position of the intestines. A large number of diagrams, sketches, photographs, and models were compared with one another till I was finally able to convert them into a common scheme, by which I have been in the habit of demonstrating the course of the intestines to students, and then immediately verifying

it on the cadaver. In doing this, it is necessary to be prepared for the variations, and these again can be classified.

WORK OF HENKE, SERNOFF AND WEINBERG.

It was generally believed that the intestines within the abdominal cavity had no definite position until a few years ago, when Henke* demonstrated that this was not the case. A glance at the various standard text-books on anatomy shows that there is a tendency among them to locate the main groups of the small intestine in fairly definite portions of the abdominal cavity. Gegenbaur† gives an illustration copied from Luschka in which the jejunum and ileum are located respectively in the upper and lower portions of the abdomen. In the text he expressly states that the jejunum is located in the upper portion of the abdominal cavity and extends down to the left iliac fossa. The ileum, however, is located in the lower portion of the abdominal cavity and in the pelvis, and extends over to the right iliac fossa. Hoffmann‡ gives an excellent illustration of the coils of the small intestine, locating the jejunum mainly in the umbilical and left iliac regions, with the ileum within the pelvis and lower abdominal regions. Similar descriptions are given by Testut§ and by Quain,‖ with the exception that they are more cautious about locating definite loops. Quain states, "the jejunum lies above and to the left side of the ileum, but the coils are so irregular that the position of any individual loop offers but little clue to the part of the intestine it belongs," while Testut states that the position of the intestine changes, due to the muscular contraction, and so on.

The first decided step in advance to locate the position of the intestine was made by Henke when he studied carefully the spaces in which the intestine may lie. He found that the abdominal cavity may be divided into four compartments, the greater of which lies within the concavity of the diaphragm and is filled with the organs which are more or less firmly fixed with ligaments. The other three compartments are separated from one another by the ridge formed by the two psoas muscles and by the vertebral column. This makes a right and left compartment and a lower compartment which extends into the pelvis. Into these three compartments the intestine must accommodate itself, and Henke thinks it has a fairly definite position. He is cautious enough, however, to state that under certain conditions the loops may shift from one space to another, but what the regularity of the position is, or what the rule of the shifting, is difficult to determine from Henke's paper. His illustrations, however, are very good, but, according to my experience, do not represent the normal type of the intestine. Of course, we could not expect them to do so, for the number of cadavers he studied carefully appears to have been but three.

Henke's method of study was to make sketches of loops of intestine and then to remove them, sketching again the loop below. By combining the drawings he finally outlined the course of the intestine from the duodenum to the cæcum. Of course, he examined a great number of intestines in fresh cadavers, but it is difficult to trace the course of the intestine in them, as the slightest disturbance will make one's result uncertain. While, therefore, he gives very little certainty regarding the course of the intestine, he states definitely that the course of the loops on the left side is horizontal to the body, while on the right side it is perpendicular.

A few years later Sernoff* studied a few cadavers more carefully and with more accurate methods than Henke, but did not verify Henke's result. Sernoff injected the cadaver with a large quantity of chromic acid, and in this way the intestine and mesentery were hardened in position. Then, after opening the abdominal cavity, a cast was made of the intestine, and finally the surface loops were stained with fuchsin. In this way the surface loops were marked after disturbing the intestine for purpose of exploration and measurement. Next the intestine was removed, showing the form and position of the mesentery which was left within the body. The method throughout is accurate, but the number of specimens is not numerous enough for any generalization of the position of the loops. Only two records of intestines in normal position are given, and although Sernoff believes that these are diametrically opposed to each other in position, I think it is not difficult to see that there is a great similarity in them. The fact that a higher loop may be on the right of a lower one in one case and the reverse in another does not necessarily overthrow a general scheme. Also, it is not of much significance regarding the general course of the intestine that in specimens 2 and 3 (he does not picture No. 2) the direction of the convolution is not horizontal above and to the left and perpendicular below and to the right.

Recently Weinberg† has studied a number of specimens in new-born infants very carefully. He gives good illustrations and descriptions of ten specimens which were studied with the method employed by Sernoff. In general, Weinberg's specimens are all after the same plan, showing that the intestine goes over and back, antero-posteriorly, beginning at the upper left side and ending in the lower right side. In seven specimens out of the ten the large upper segment of the jejunum lay in the left upper part of the abdominal cavity. In three specimens, only a short portion of the jejunum lay in the left hypochondriac fossa and the rest came up in contact with the ventral abdominal wall. The direction of the loop in this region was mainly transverse to the body, and, in general, the extent of them was about two-fifths of the length of the small intestine. Following these loops there is a group of irregular convolutions which lie in the left iliac fossa, and include the middle fifth of the intestine. Then the intestine crosses the left psoas muscle, and the remaining two-fifths of the small intestine lie between this and the right psoas, as well as on the right side of the abdominal cavity. The direction of the convolutions of this portion is mainly perpendicular. The extent of the intestine which comes in contact

* Henke, His's Archiv, 1891.
† Gegenbaur, Anatomie, 1890, Bd. 2, S. 59.
‡ Hoffmann-Rauber, Anatomie, 1886, Bd. 1, S. 557.
§ Testut, Anatomie, 1894, t. 3, p. 505.
‖ Quain, Anatomy, 1896, vol. 3, pt. 4, p. 103.

* Sernoff, Internat. Monatsch. f. Anat. u. Phys., 1894.
† Weinberg, Internat. Monatsch. f. Anat. u. Phys., 1896.

with the anterior abdominal wall is about one-third of its whole length, which corresponds with the measurements given by Sernoff for the adult.

In general, Weinberg's results confirm Henke's and give for my purpose the important intermediate stage between the fœtus and the adult. I have also examined the intestine of a number of new-born babies after they had been hardened *in situ* in formalin or in carbolic acid and can confirm the work of Weinberg.

In describing the direction of the loops of the intestine in the various portions of the abdominal cavity it is not well to state the direction of the external loop to the body cavity, for this loop may be only the connecting link between two more important loops above and below. The main loops must be isolated whether they are superficial or deep, and the plane of the circle which they describe makes the general direction of the loop. If the intestine makes a continuous spiral, then the direction of any one of the loops is about parallel with the circles the loops describe; but if the spiral reverses itself, then the connecting loop is at right angles with the plane of the circles. If this is not considered, it may be that the superficial loops are perpendicular, while the main loops are transverse to the body axis.

POSITION OF THE INTESTINE IN FORTY-ONE CADAVERS.

The cadavers had all been carried in the supine position for at least two kilometers over the rough cobblestones of Baltimore before they were delivered at the laboratory, and this shaking may account for the regularity of the arrangement of the intestine. They were then injected with about 1.5 to 2 kilograms of carbolic acid crystals in the form of a 33 per cent. solution into the femoral artery. This coagulates completely the abdominal and thoracic viscera. After that the bodies were frozen and some of them were not studied until two years later, while most of them were opened at about the end of a year. The older bodies are preferable, as the surplus water has evaporated and the tissues are fairly dry and somewhat hard.

In all of these specimens the general direction of the intestine was diagonally across the abdomen from the left hypochondriac space towards the right iliac fossa, usually diverging once or sometimes twice towards the right side of the abdomen and always towards its end, into the cavity of the pelvis.

The general form and position of the mesentery is well shown in Fig. 17, as well as in Figs. 5 and 8 by Sernoff. These figures show the large curves made by the mesentery to attach itself to the loops, first on one side of the root of the mesentery and then on the other. I have tried to follow rather the greater groups of convolutions, for it is hopeless to attempt to number every individual loop.

In 21 of the specimens the arrangement of the loops was after the same plan; therefore I shall consider this the normal, and the arrangements of the intestine in the other specimens as variations of this plan. In these specimens the jejunum first arranged itself into two distinct groups of loops situated well up in the left hypochondriac region. Each group made more than a complete circle, and both of them came in contact with the anterior abdominal walls. They are marked 2 and 3 respectively in Fig. 16, the loop 2 being the one which communicates with the duodenum. After this the intestine passes through the umbilical region to the right side of the body. This loop is marked 4 in the figure. Then the intestine recrosses the median line to make a few convolutions in the left iliac fossa (5), after which it fills the pelvis and lower abdominal cavities between the psoas muscles (6). The course of the intestine which has been pictured in Fig. 16 is given in Fig. 18.

When now this arrangement of the intestine is compared with that of fœtuses XXXIV and XLVIII, as well as with Weinberg's specimens, it is fairly easy to see the gradual transformation of XXXIV into the adult type. Fig. 12 still shows the intestine about equally distributed on both sides of the body, with the cæcum still very high. In Fig. 14 there is already a marked descent of the cæcum towards the future pelvis. In comparing these two figures it is to be observed that Fig. 12 is a ventral view and Fig. 14 a view from above. The outlines of the stomachs in the two figures will show from what point the models have been drawn.

When we pass from these two specimens to the figures of Weinberg, we see a similarity between them and most of his figures, but in a number of them the intestines have begun to shift more and more. In general there is a tendency for the irregular lines of mesentery to bend towards the left iliac fossa, for, with the descent of the cæcum, the whole mesentery is rotating towards the left side. Weinberg's Fig. 18 shows this well. Hand in hand with this movement one or more loops move towards the right side of the body, as his Figures 11 and 19 show. As yet there is no marked pelvic cavity to take the lower end of the ileum, and as soon as the pelvis is large enough to hold it, we can easily imagine the intestine pictured by Weinberg in Figs. 5, 9, 11, 16, 17, 18 and 19 to be converted into my Fig. E by a simple descent of the ileum into the pelvic cavity. The other few specimens may be considered as variations.

In a shifting of this sort it is probable that the middle loops of the intestine would be transferred to the right side, while the upper half would remain on the left side, and the lower half in the pelvis and lower abdominal regions. According to Sernoff's three measurements, on an average 41 per cent. of the length of the intestine is on the left side, 41 per cent. in the pelvic cavity and about 18 per cent. on the right side. In embryos IX, X, VI and XLV the loops 2, 3 and 4 together are shorter than the loops 5 and 6, while in XXXIV and XLVIII, these first three groups are somewhat greater in length than the lower two. In the younger embryos it was the ileum which grows more rapidly, while in the older embryos the jejunum is beginning to overtake the ileum. So from these measurements, as well as from the indication in Figs. 12 and 14, it is the loop 4 which is destined to cross the middle line and to take its position on the right side of the body.

Henke showed that it is not difficult to separate the intestine into two great groups, the dividing line of which is the left psoas muscle. This, usually, is also the limit between the loops 4 and 5, as shown in Fig. 16. The diagrammatic

PLATE 1.

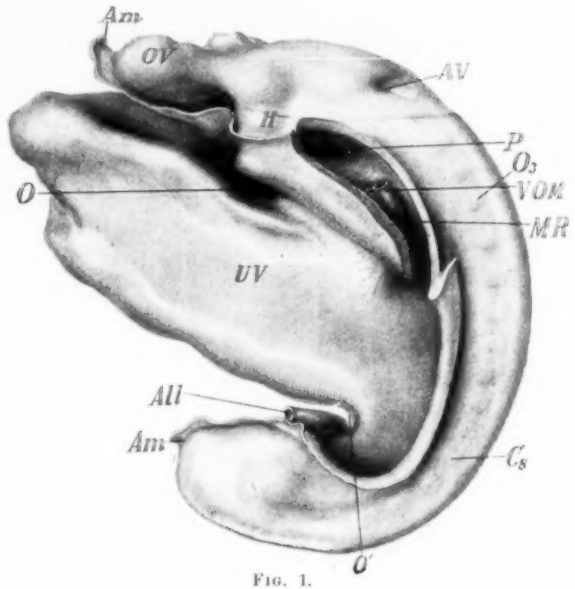

FIG. 1.

FIG. 3.

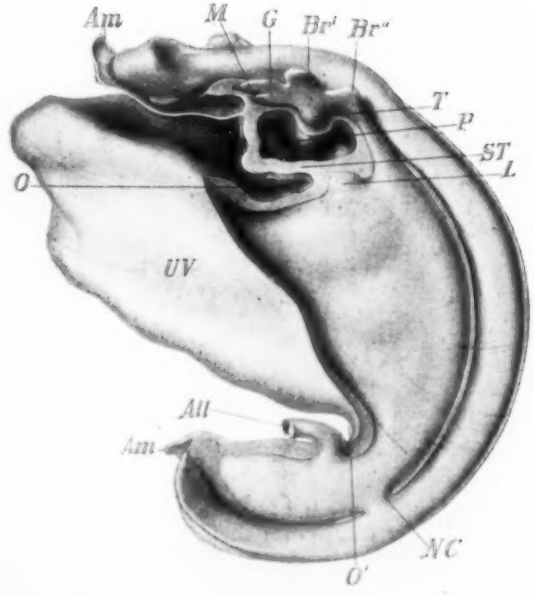

FIG. 2.

M. Brödel del.

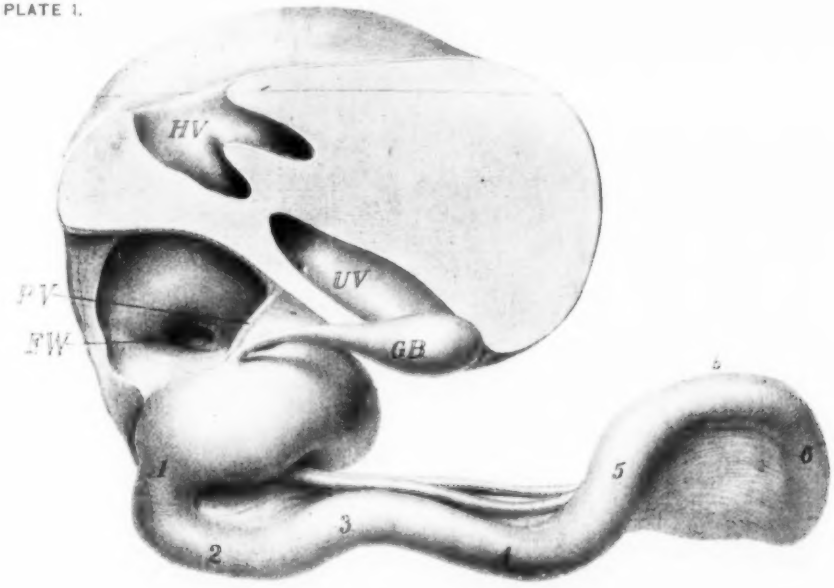

FIG. 4.

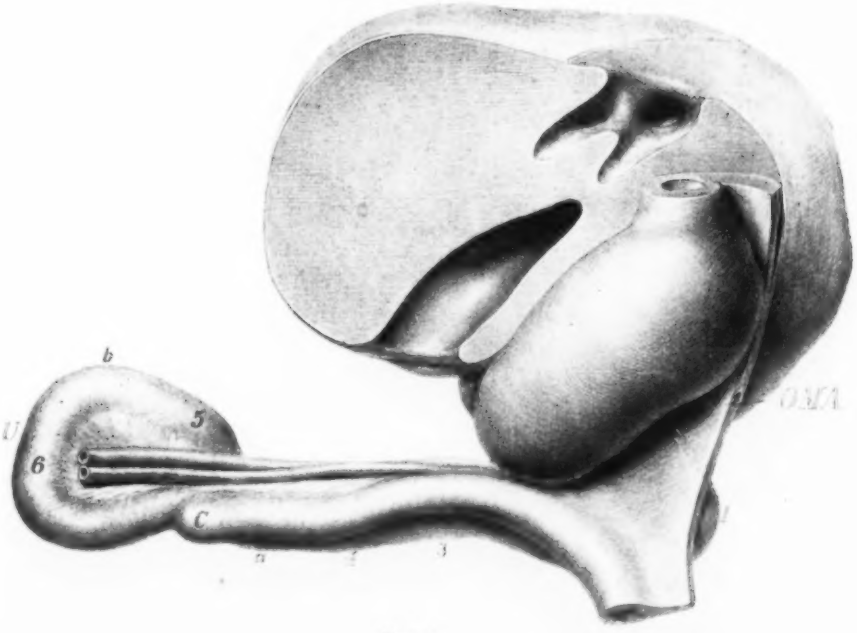

FIG. 5.

PLATE II.

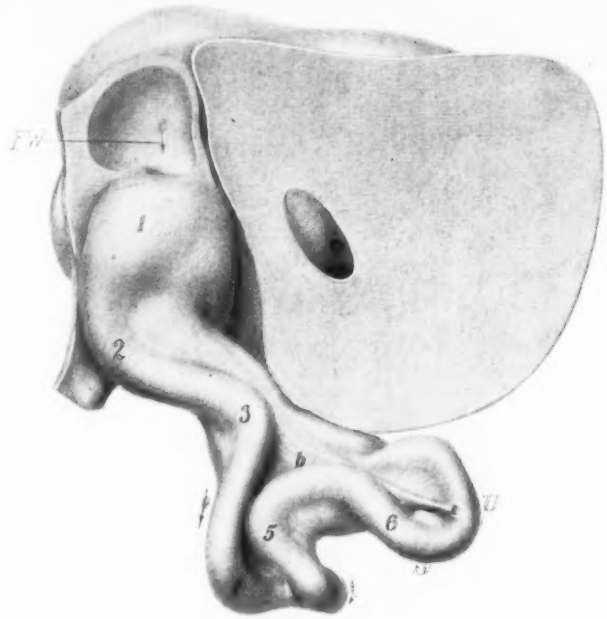

FIG. 6.

FIG. 8.

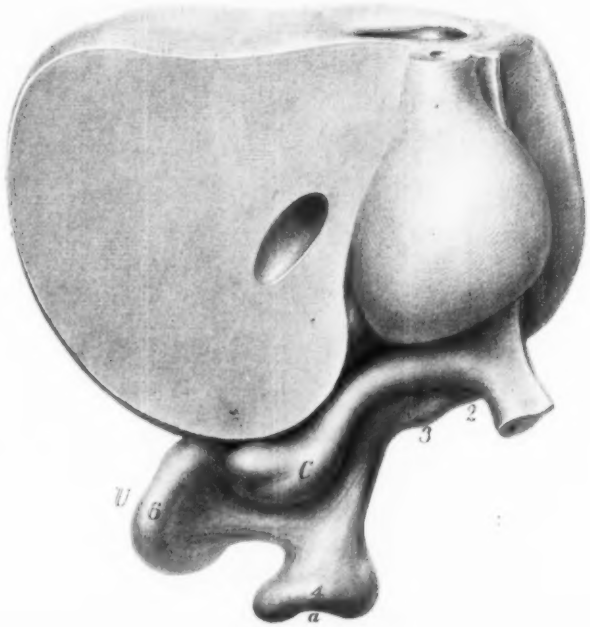

FIG. 7.

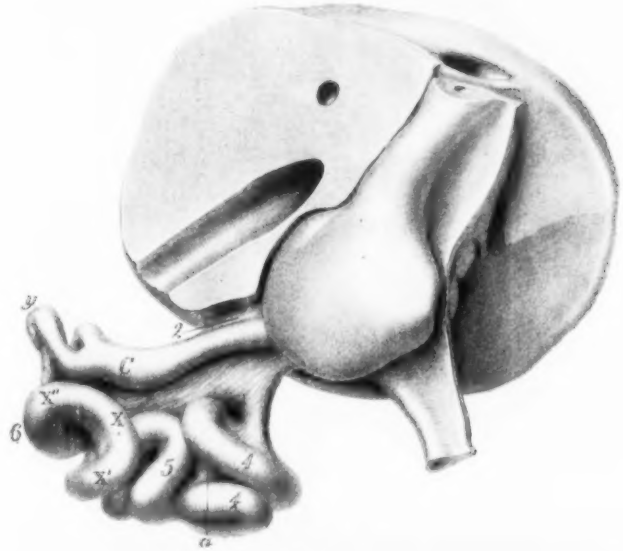

FIG. 9.

M. Bridel del.

Fig. 7.

M. Brödel del.

Fig. 9.

PLATE III.

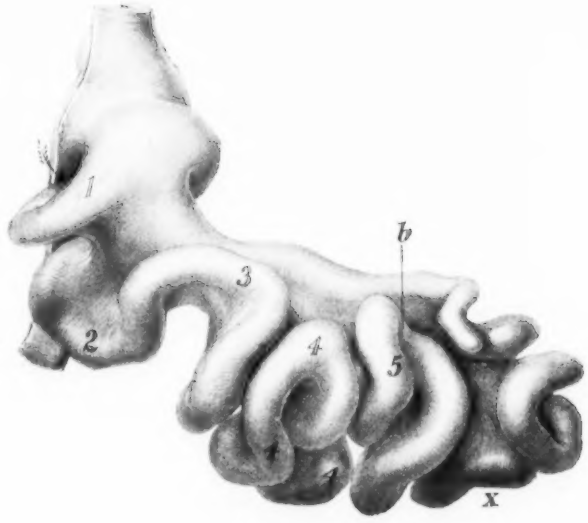

Fig. 10.

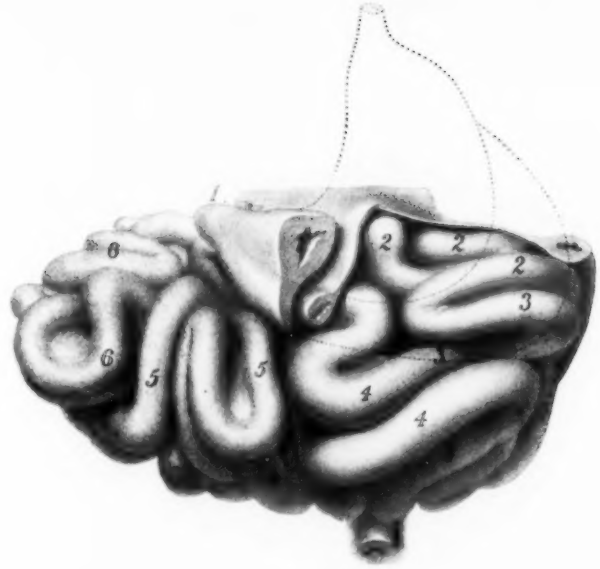

Fig. 12.

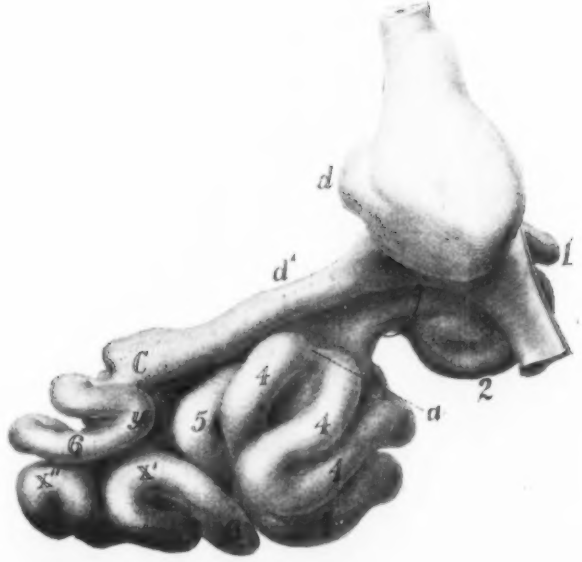

Fig. 11.

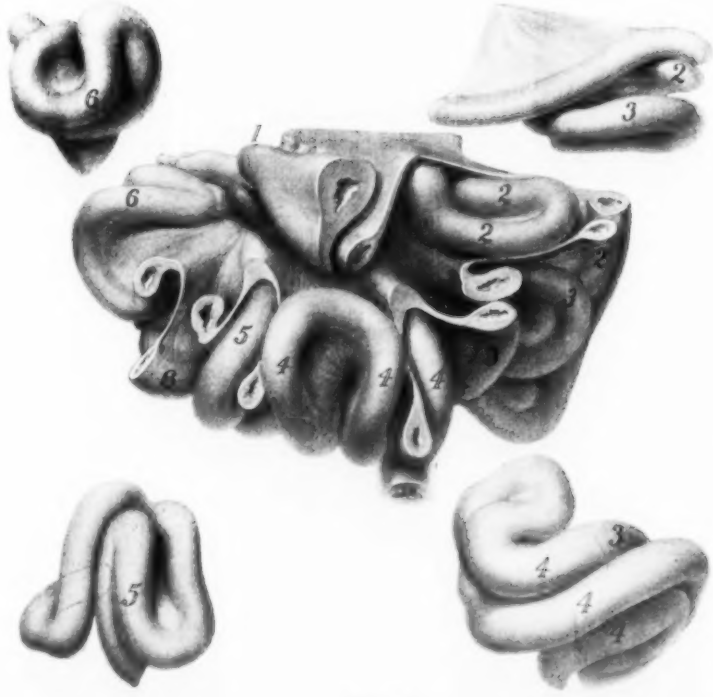

Fig. 13.

M. Brödel del.

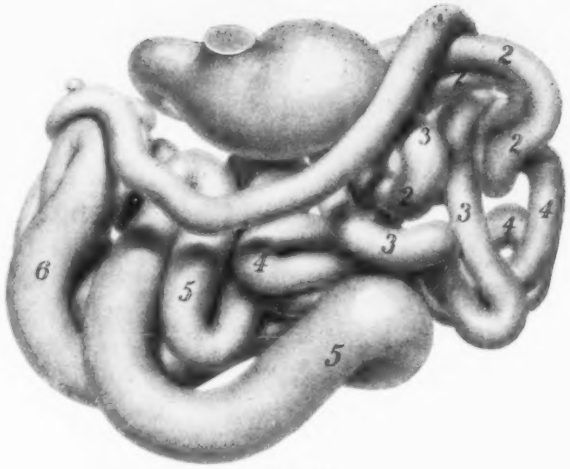

Fig. 14.

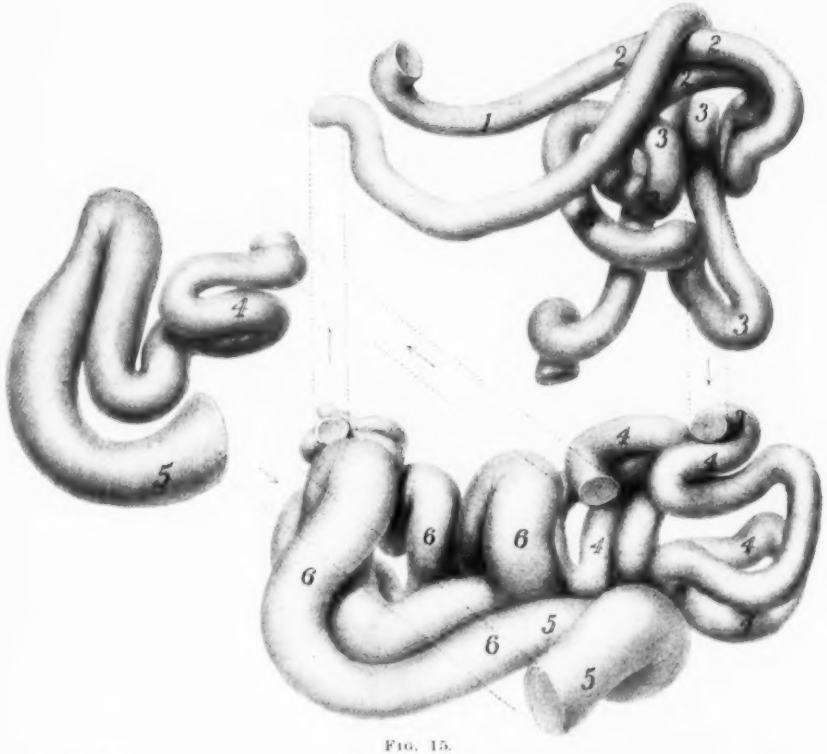

Fig. 15.

M. Brödel del.

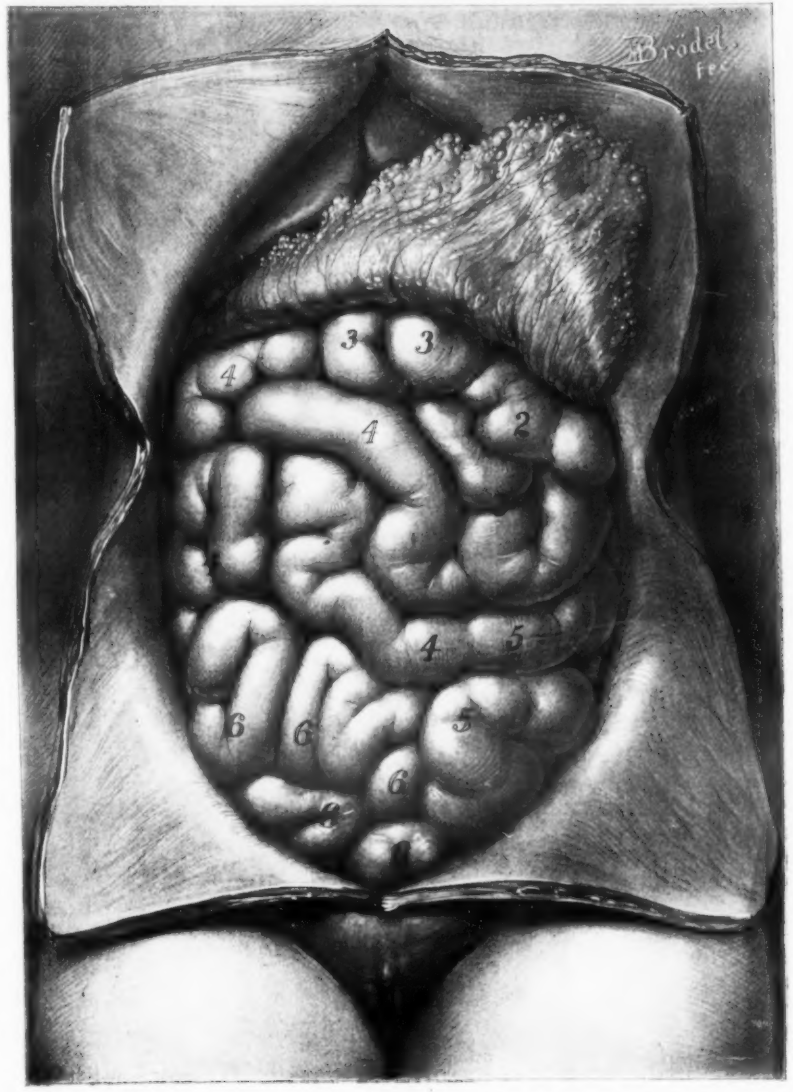

Fig. 16.

M. Bruidel del.

PLATE V.

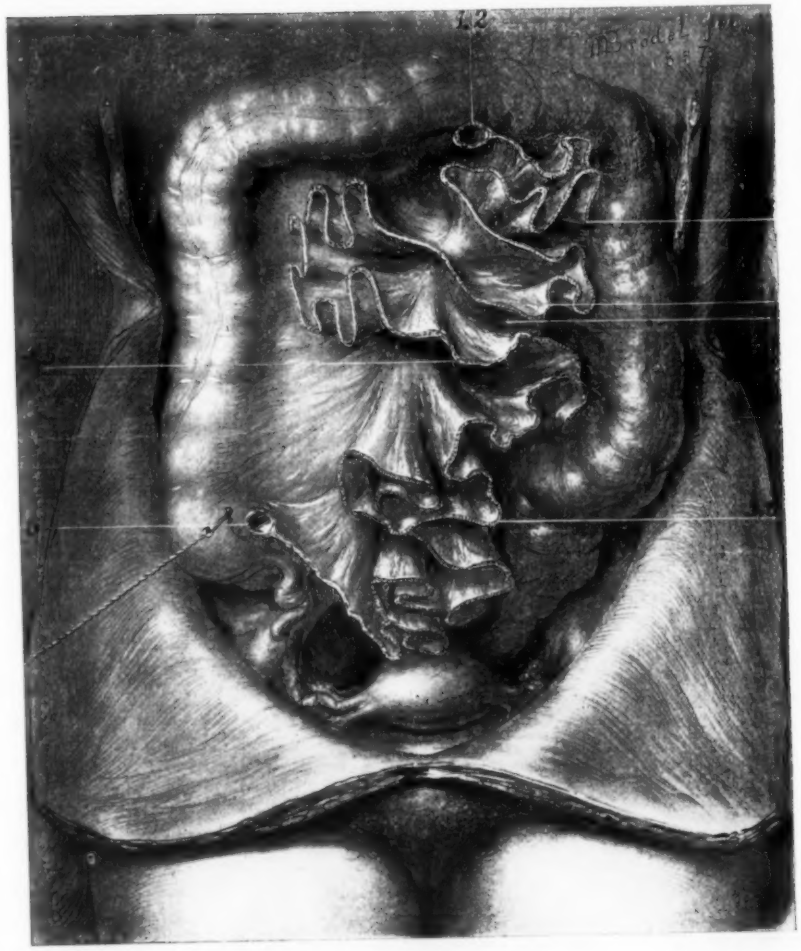

FIG. 17.

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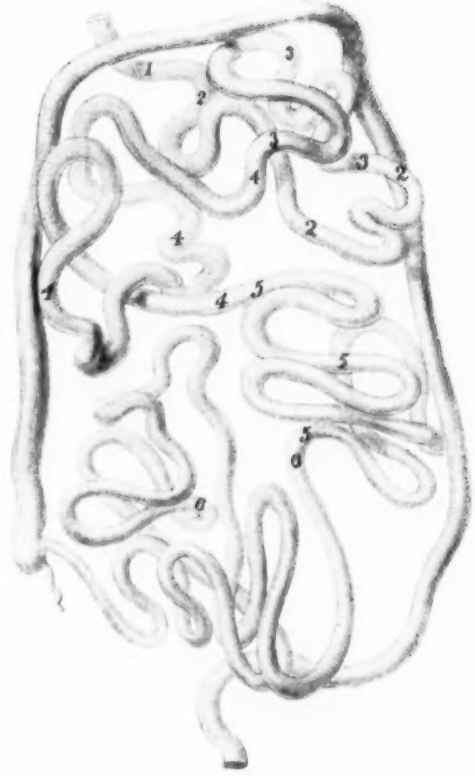

FIG. 18.

Fig. E shows this still better between loops 4 and 5. When the loops 5 are within the pelvis this separation made by the psoas is still more marked. Also in those specimens in which the position of the intestine is as in Fig. E, the loop 4 can be lifted towards the left side, making a beautiful demonstration of the attachment of this loop. A glance at Fig. 17, as well as at Sernoff's Figs. 5 and 8, will easily explain why this should be so.

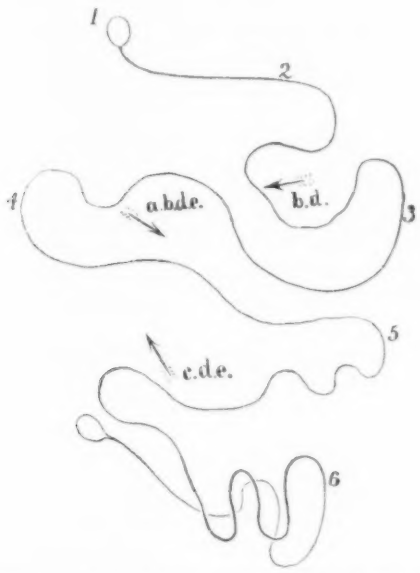

FIG. E.—Scheme of the intestine. The arrows indicate the variations. The variations a and bb were most frequent; the variation e least frequent.

VARIATIONS IN THE POSITION OF THE INTESTINE.

One of the most common variations I have found is one in which there were no intestines on the right side of the peritoneal cavity. The loop 4 had been transferred to the left side of the body, as indicated in Fig. E by the arrow a. Otherwise the intestine had its usual position. It is this loop which is so easily isolated and, probably on this account, it is readily displaced by an enlarged cæcum or ascending colon. It may possibly be that this loop can be shaken to the left side, and this could easily be tested by experiment. In one of these specimens the sigmoid flexure of the colon filled the right side of the abdominal cavity.

The second variation, as well as the first, occurred six times. It is marked by the arrows bb in Fig. E. The loop 4 was again displaced to the left side, and the loops 2 and 3 were displaced to the right side. In other words, the very upper part of the jejunum formed the loop on the right side of the body.

The third variation occurred five times. In these specimens the intestine had its normal position, with the exception that an additional loop arose out of the pelvis and filled a portion of the right side of the body, as indicated by the arrow c. Sernoff's specimen, pictured in Figs. 3, 4 and 5, is to be included with this group.

The next variation occurred two times. It is indicated by the arrows d in Fig. E. The large loop 4 was again drawn to the left side, and the space it formerly occupied was filled by two loops, one from the upper part of the jejunum, and the other from the lower part of the ileum.

The last variation occurred once. It is marked by the arrows e. The loop 4 was displaced and its place taken by a large loop which arose from the ileum within the pelvis. Henke's specimen B seems to belong to this group, if I can judge by his illustrations.

MARKED VARIATIONS.

The variations given above all fit within the common scheme and can easily be explained. In all of my specimens I found but one extreme variation, and in this the intestine crossed the middle line at the beginning of the jejunum and then filled the right fossa. From here it descended immediately into the pelvis and filled it and the lower abdominal cavity completely. Then it left the pelvic cavity and filled the left fossa, extending up to the beginning of the duodenum. When it had reached this point it took a fairly direct course along the descending colon over the floor of the pelvis, and passed directly to the cæcum. Henke* has also described a variation practically identical with this. Weinberg† has also described one similar to this, only that the jejunum descends immediately to the pelvis and then gradually rises to the left side, and finally over to the right side. What kind of a mechanism can bring about this extreme variation is not possible to state.

It could be asserted that these few instances of marked variations indicate the normal, but in my specimens it is one in forty-two; in Weinberg's, one in ten; and in Henke's specimens it is not stated how many cadavers were examined carefully.

SHIFTING OF THE INTESTINE.

Henke has stated that the loops of the intestine may shift from one of the abdominal fossæ to the other, and, no doubt, this is true. We are familiar with the fact that a distension of any of the pelvic viscera pushes all of the loops of intestine out of the pelvis,‡ and emptying it again allows the loop to descend to the floor of the pelvis. So likewise a distension of the colon or a certain number of loops of small intestines will displace a certain number of loops from their natural position. Since, however, the intestine was located after one plan in 41 cadavers, I do not think it probable that ordinary shaking will displace any number of loops. Pure mechanical disturbances, as by returning the intestines after operation, will also be overcome by the intestines shifting about to their normal position, guided by the attachment of the mesentery, its length and the space within the abdomen. To give this last question a thorough test I made a number of experiments upon dogs. In these animals the intestine is closely rolled up in a very regular fashion below the stomach, and the whole is carefully tucked in by the very large omentum. Upon opening an animal, one is struck with the neatness and accuracy of the

*Henke, His's Archiv, 1891, p. 101, Taf. IV, Fig. 12.

†Weinberg, Internat. Monatsch. f. Anat. u. Phys., 1896.

‡Among others, Garson, His's Archiv, 1878.

adjustment of the omentum, and it is easily disturbed by handling. When, however, the intestine and omentum are withdrawn through an abdominal wound, they are disturbed to such an extent that it is impossible to return them to the abdominal cavity as they were found, with the omentum covering them. After the intestines have been pushed into the abdominal cavity in a haphazard way and the animal sewed up, using all antiseptic precautions, the loops as well as the omentum readjust themselves as they were before, provided no marked inflammation takes place. So in the dog, the intestine and omentum seek their normal position after they have been disturbed.

PLATE I.

FIG. 1.—Profile view of Embryo No. XII. Enlarged 38 times. The body wall over the heart has been cut out. Am, amnion; UV, umbilical vesicle; OV, optic vesicle; AV., auditory vesicle; O_3, third occipital muscle plate; C_8, eigthth cervical muscle plate; H, heart; P, pericardial cavity; VOM, omphalo-mesenteric vein; MR, membrana reuniens; D, D′, openings which connect the peritoneal cavities of the two sides with each other.

FIG. 2.—Same as Fig. 1, but half of the model has been removed to show the extent of the ectoderm and entoderm. Br′, Br″, first and second branchial pouches; M, mouth; S, Seessel's pocket; T, thyroid; L, liver; NC., neurenteric canal.

FIG. 3.—Intestine of Embryo II, viewed from the right side. Enlarged 34 times. C, cæcum; M, mesentery; y, remnant of yolk sac.

FIGS. 4 and 5.—Intestine and liver of Embryo IX. Enlarged 25 times. C, cæcum; OMA, omphalo-mesenteric artery; HV, hepatic vein; UV, umbilical vein; PV, portal vein; FW, foramen of Winslow; GB, gall bladder.

PLATE II.

FIGS. 6 and 7.—Intestine and liver of Embryo X. Enlarged 12½ times. U, position of umbilical vessels; C, cæcum; FW, foramen of Winslow.

FIGS. 8 and 9.—Intestine and liver of Embryo VI. Enlarged 12½ times.

PLATE III.

FIGS. 10 and 11.—Intestine and stomach of Embryo No. XLV. Enlarged 16 times.

FIGS. 12 and 13.—Intestine of Embryo No. XXXIV. Enlarged 4 times. Viewed from the ventral side. In Fig. 13 certain loops have been lifted off to show the deeper loops.

PLATE IV.

FIGS. 14 and 15.—Intestine of Embryo No. XLVIII. Enlarged 2½ times. The view is from the ventral and cephalic side of the model. The mesentery was not included in the model. Fig. 15 is a dissected model to show the deeper loops. The lower part of the intestine is enormously distended with cell debris, etc., showing that vermicular action is present at this early stage.

FIG. 16.—Usual position of the intestine in the abdominal cavity. Although this is an actual specimen, it represents the condition in twenty-one out of forty-one cadavers. The numbers in the figure mark the parts which are homologous with the loops correspondingly numbered in the other figures.

PLATE V.

FIG. 17.—Usual position of the mesentery.

FIG. 18.—Course of the intestine. This figure is taken from a model made from the same cadaver from which Figs. 16 and 17 were drawn.

ON THE HISTOGENESIS OF THE STRIATED MUSCLE FIBRE, AND THE GROWTH OF THE HUMAN SARTORIUS MUSCLE.

BY JOHN BRUCE MACCALLUM.

(From the Anatomical Laboratory of the Johns Hopkins University, Baltimore.)

In a previous paper* I described the structure and histogenesis of the heart muscle cell of mammals. The process of development, as demonstrated in embryo pigs, was found to be quite definite, and in order to complete this work I have studied the heart muscle of a series of lower vertebrates, taking representatives from the various large classes. The definite stages in the histogenesis of the muscle cell, confirmed by its comparative histology, made it seem possible to determine the method of growth of a muscle as a whole; that is, to learn by what means a small embryonic muscle gradually becomes large, as in the adult. Such a study of the heart seemed to present many difficulties which that of a simpler system of muscles would not. I therefore turned to the striated muscle of other parts of the body, the so-called voluntary muscles, and with this problem in view I studied the histogenesis of the striated muscle fibre of the thigh in embryo pigs. In these a process was demonstrated which proved to be essentially the same as that found in heart muscle, with differences made necessary by the difference between the respective adult tissues. Knowing, then, the course of growth of the individual muscle cells, I have endeavored to determine the relation of this to the growth of the muscle as a whole. In order to begin with the simplest problem, I have chosen the sartorius muscle, as it seemed to show less complexity of structure than many other muscles. Two sides of this problem presented themselves. On the one hand it was necessary to determine how far the growth in size of the muscle as a whole was caused by increase in the number of fibres, and how far it was due to a mere growth in size of the individual cells. On the other hand it was necessary to make out the relation between the various stages in the histogenesis of the muscle cell and these two methods of growth. These problems I have endeavored to solve by the study of a series of human embryos, using the sartorius as the

*J. B. MacCallum, On the Histology and Histogenesis of the Heart Muscle Cell. Anatomischer Anzeiger, Jena, Bd. xiii, No. 23, 1897, S. 609-620.

type of a simple muscle. For the sake of clearness I will give the results of this work under three headings, as follows:

I. Synopsis of the work already done on the histogenesis of the heart muscle cell, supplemented by a study of its comparative histology.

II. The histogenesis of the voluntary striated muscle cell.

III. The growth of the sartorius muscle and its relation to the histogenesis.

I.—HISTOGENESIS AND COMPARATIVE HISTOLOGY OF HEART MUSCLE.

As described in the article referred to above, the adult human heart muscle is made up of rhomboidal branching cells whose processes come together end to end. The protoplasm of each cell consists of a number of darkly staining columns, running longitudinally, which are separated by unstained substance. The columns are commonly called fibril bundles, and the unstained substance is the sarcoplasm. With special methods of staining, particularly by Kolossow's osmic acid method, a definite relation can be made out between these two parts of the cell. The fibril bundles present regular striations in the form of darkly staining lines. Narrow striations, the so-called Krause's membranes, alternate with broader bands which are known in voluntary muscle as Brücke's lines. The Krause's membranes, however, do not belong to the fibril bundles alone. They can be seen also extending across the sarcoplasm, as shown in Fig. 1. The sarcoplasm is thus divided into compartments which are limited horizontally by membranes continuous with the narrow striations on the fibril bundles. In cross section (Fig. 2) the muscle fibre is seen to be made up of dark masses, the cross-sections of fibril bundles, separated by sarcoplasm which is divided into definite circular or polygonal areas. The compartments of the sarcoplasm, then, are disc-shaped, and I have proposed for them the name sarcoplasmic discs. As described, they are bounded by membranes which are continuous with the fibril bundles at definite points, namely, at the narrow striations or Krause's membranes. It will then be seen that there is a definite network in the cell made up of the fibril bundles and the membranes bounding the sarcoplasmic discs.

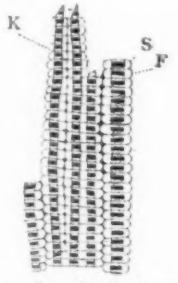

FIG. 1.—Longitudinal section of Adult Human Heart Muscle. *K*, Krause's membrane; *S*, sarcoplasmic disc; *F*, fibril bundle.

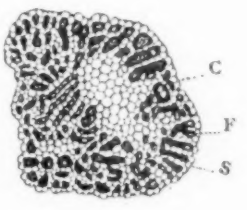

FIG. 2.—Cross-section of Adult Human Heart Muscle. *C*, central sarcoplasm; *F*, fibril bundle; *S*, sarcoplasmic disc.

The stages in the embryo leading up to this adult structure explain the relation of the fibril bundles to the sarcoplasm. The earliest stage in the development shows an irregular network in the cell protoplasm with no fibril bundles. This network tends to become more and more regular until the meshes are of the form of large discs. Some of these break up into smaller ones, and in the nodal points of the network there is an accumulation or differentiation of its substance, giving rise to longitudinally disposed masses. These become what in the adult are known as fibril bundles, and the discs left are the sarcoplasmic discs. This formation of fibril bundles takes place first at the periphery of the cell, so that those which are the latest to appear are nearest the centre of the cell. It is apparent, then, that the continuous network spoken of in the adult fibre, made up of the fibril bundles and the membranes bounding the sarcoplasmic discs, is developed directly by a process of differentiation from the primitive protoplasmic network of the embryonic cell. The gradual acquirement of a special function has so altered this network that a complicated structure is formed out of an extremely simple one.

The study of the heart muscle of lower animals gives an interesting repetition of some of the stages of this process. Although the structures met with in the comparative histology of the organ do not make up an uninterrupted sequence as in its histogenesis, yet there is a sufficient resemblance to confirm the results obtained in embryonic tissues. Hearts from animals representing the various large groups of vertebrates were studied. Of the fishes several species were obtained, among which were the larval lamprey (Ammocœtes), the adult lamprey, and several kinds of Teleosts. The Amphibians were represented by the frog and the toad, while of the reptiles the snake and turtle were used. Several species of birds were studied, such as the English sparrow, the crow, and the common fowl.

In the heart of Ammocœtes the muscle cells are small and spindle-shaped. In some of them no fibril bundles can be seen, but most of the cells show a single row of very narrow fibril bundles at the periphery. The rest of the cell is made up of sarcoplasmic discs. In the lamprey the structure is similar, while in the higher fishes, such as the pickerel, the cells are considerably larger and the fibril bundles are more conspicuous. In longitudinal sections the individual fibril bundles are quite similar to those in adult mammalian muscle. The same striations are present, and the same relation of these to the sarcoplasm exists. In the frog and toad the structure of the heart muscle differs only slightly from that described in fishes. The cells are larger, and the fibril bundles are closer together, tending to form large irregular columns. The nucleus is in the centre of the cell, and the fibril bundles are only at the periphery. The heart muscle of the Reptilia, as shown in the turtle and snake, is made up of cells which are not markedly different from those of the Amphibian heart. The fibril bundles at the periphery of the cell are large and conspicuous, and in many cells there are smaller ones more centrally placed. In the birds, however, there is a very decided advance on the structures described so far. The cells are very large, almost as great as the adult mammalian fibre. In cross-section they resemble the structure described in mammals. The nucleus is in the centre and the rest of the

cell is almost filled with fibril bundles. These are in the form of flat bands around the periphery, as in mammalian muscle, and are separated by sarcoplasmic discs. There is a very great difference between these cells and those found in the hearts of Fishes, Amphibians and Reptiles. As regards the structure of the heart muscle, then, the classes of Vertebrates are divided into two groups, one comprising the Fishes, Amphibians and Reptiles, and the other the Birds and Mammals. It will be noticed that these groups are the cold-blooded and warm-blooded animals respectively; and it is possible that in addition to the control of the temperature by the central nervous system, there is a relation between the heat regulation and the degree of development of the circulatory system. The mammalian embryo *in utero* resembles the cold-blooded animals in the fact that its temperature is the same as that of its surroundings. They are under similar conditions in this respect, and the structure of the heart muscle is almost identical. Although the transition from the structure of the heart muscle of lower to that of higher animals is not perfectly gradual, yet the comparative histology corresponds roughly with the histogenesis of the cell. The Fishes, Amphibians and Reptiles, which in other respects are clearly lower than the Mammals and Birds, possess also an embryonic type of heart muscle. The heart of an adult fish, for example, is made up of cells which are almost identical with an early stage in the development of the mammalian fibre. While the comparative anatomy and the embryology of many organs run parallel to one another, it is interesting to note that this same relation holds good even in the internal structure of a single cell, and that the most minute details of the cell structure in the adult heart muscle of the lower animals are identical with those in embryonic mammalian tissue.

II.—HISTOGENESIS OF THE VOLUNTARY STRIATED MUSCLE FIBRE.

In order to determine the course of development of the voluntary striated muscle cell I have used a series of human embryos and one of embryo pigs. Of the former I used the sartorius muscle in each case, and in the latter the muscles in the front of the thigh. The human series consisted of embryos of the following lengths in millimeters from vertex to breech: 10, 30, 75, 102, 130, 170 and 200. The series of pig embryos was made up of specimens of the following lengths in millimeters: 25, 34, 45, 57, 64, 70, 75, 100, 125 and 150. The sartorius of an embryo rabbit 35 mm. in length was also studied.

The embryos, which were obtained in a fresh condition, were treated according to Kolossow's osmic acid method,* and the sections afterwards stained in safranin. Those which were already hardened in formalin, alcohol, or Müller's fluid, were cut in paraffin, and the sections treated by a method somewhat similar to Kolossow's. They were immersed in 2 per cent. osmic acid for three or four minutes, and then transferred to Kolossow's reducing fluid and left until the precipitation was complete. They were then stained in safranin to differentiate the nucleus. Sections stained in this way show the protoplasmic structure with great clearness.

In an embryo pig 25 mm. long the voluntary muscle has quite an undifferentiated character. The sartorius in a cross-section of the leg cannot be recognized with certainty. There are merely small groups of spindle-shaped cells with a loose connective tissue between. In the muscle cells there are no fibril bundles, and the protoplasm is very scanty as compared with that in the adult cell. If in a cross-section the cell has its nucleus cut through, the protoplasm is hardly visible. It is seen only as a narrow rim around the centrally placed nucleus. The cross-section of a cell above or below the nucleus shows a definite network which divides the cell into small circles. These correspond with the structures spoken of as sarcoplasmic discs. This is shown in Fig. 3.

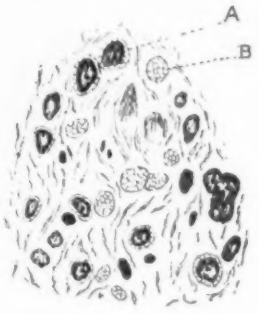

FIG. 3.—Cross-section of Voluntary Muscle from the Thigh of an Embryo Pig, 25 mm. long. *A*, cell showing the nucleus; *B*, cell showing sarcoplasmic discs.

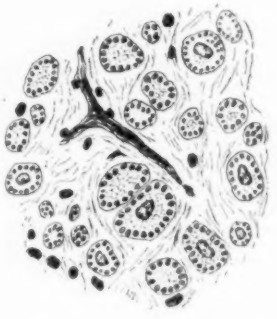

FIG. 4.—Cross-section of Voluntary Muscle from the Thigh of an Embryo Pig, 45 mm. long, showing fibril bundles at the periphery of the cells.

The muscle of an embryo pig 34 mm. in length is somewhat farther advanced in development. The bundles of cells making up the individual muscles are quite distinct and separate. The cells themselves show a centrally placed nucleus, and protoplasm which is very slightly differentiated. In some places fibril bundles can be made out at the periphery of the cell, but these are not very distinct.

In an embryo pig 45 mm. in length the muscle cells contain definite fibril bundles. These are present in a single row around the periphery of the cell, as shown in Fig. 4. The nucleus is still situated in the centre of the cell. The protoplasm near the nucleus contains no fibril bundles, and is divided into sarcoplasmic discs as described before. In longitudinal sections the fibril bundles are seen to be definitely related to the sarcoplasm in the way described above. The horizontal boundaries of the sarcoplasmic discs are membranes continuous with the fibril bundles at the narrow striations.

Very similar cells are found in the muscle of an embryo 57 mm. long. The fibril bundles, however, are somewhat more conspicuous. In embryos 64 mm. and 70 mm. in length the muscle cells contain, in addition to the peripheral row of fibril bundles, scattered fibril bundles nearer the nucleus. In many cells nuclei are seen, both at the periphery and in the centre.

*A. Kolossow. Ueber eine neue Methode der Bearbeitung der Gewebe mit Osmiumsäure. Ztschr. f. wissensch. Mikr., Brnschwg., Bd. ix, 1892-3, S. 38-43.

In the muscle cells of an embryo pig 75 mm. long, the peripheral and central nuclei are seen very clearly. These differ somewhat in appearance. The peripherally placed nucleus stains deeply and uniformly, and has a solid appearance. The central nucleus, however, is large and vesicular. It possesses a definite nuclear membrane, and the chromatin network is delicate and distinct, as shown in Fig. 5. In some places the outline of this nucleus grows irregular. What finally becomes of it it is difficult to say. The nuclei in adult muscle cells are all peripherally placed, and have an appearance resembling the peripheral nucleus described here.

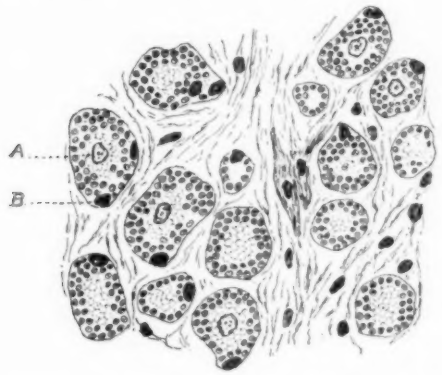

FIG. 5.—Cross-section of Voluntary Muscle from the Thigh of an Embryo Pig, 75 mm. in length. *A*, central vesicular nucleus; *B*, peripheral solid nucleus.

In a pig 100 mm. long the appearance of the muscle cells is not essentially different. The fibril bundles are more numerous and somewhat closer together. The muscle cells of an embryo 150 mm. in length, however, are entirely filled with fibril bundles. The sarcoplasm is not abundant. In some of the cells the central nucleus cannot be made out, while in others it is still present.

In adult muscle the nuclei are all at the periphery of the cell. In longitudinal sections the fibre consists of fibril bundles separated by a very small amount of sarcoplasm. The fibril bundles possess alternating narrow and broad striations. In many cases the narrow striation (Krause's membrane) can be seen extending across the sarcoplasm, dividing it into compartments. This is approximately the same structure as that which has been described in heart muscle. In the latter, however, the sarcoplasm between the fibril bundles is so abundant that the narrow striations form disc-shaped compartments, or sarcoplasmic discs. In voluntary muscle the sarcoplasm is very scanty, and the discs are so encroached upon by the growth of the fibril bundles that they are hardly recognizable. As in heart muscle, the lines dividing the sarcoplasm are continuous with the fibril bundles at the narrow striations.

The course of the development, as shown in the series of human embryos, is made up of stages which are very similar to those described in the embryo pig. In human embryos 10 mm. and 30 mm. in length the muscle cells contain no fibril bundles. In embryos 75 mm. and 102 mm. long there is a single row of fibril bundles around the periphery of the muscle cell. The nucleus is of a vesicular character and is situated in the centre of the cell. In an embryo 130 mm. long the muscle cells contain a vesicular central nucleus and one or more solid deeply staining peripheral ones. There are fibril bundles in the central part of the cell as well as at the outside. The muscle of an embryo 170 mm. in length is made up of cells which are very similar to those of an embryo pig 150 mm. long. The cells are filled entirely with fibril bundles, and the centrally placed nucleus is not often present. In older embryos, in the new-born, and in the adult subjects, the nuclei of the muscle cells are all at the periphery.

The course of development, then, seems to be quite definite. Beginning with a cell which contains only a protoplasmic network, the extremely complex voluntary muscle fibre is gradually formed. The first step is an accumulation of the network at definite places around the periphery of the cell, giving rise to fibril bundles. This accumulation takes place in the angles of the network, so that the meshes remain as discs between the fibril bundles. The membranes, bounding these discs horizontally, are continuous with the narrow striations on the fibril bundles. The formation of fibril bundles goes on until they occupy a large part of the cell. The sarcoplasm in this way becomes gradually replaced, and in the adult cell it is very inconspicuous. At the same time the nuclei undergo changes. The cell which at first contains only a centrally placed nucleus acquires other nuclei which are situated at the periphery. It is possible that the latter are derived from the centrally placed nucleus which is finally lost.

It seems that the same hypothesis is applicable here as was suggested for the development of heart muscle. It simplifies the conception of the structure of striated muscle very greatly to consider the fibril bundles and the membranes bounding the compartments in the sarcoplasm, as derived from the primitive network found in the muscle cells of very young embryos.

These results show that the same process of growth takes place in all kinds of striated muscle cells. The adult structure of voluntary muscle is, however, somewhat different from that of heart muscle, and as a consequence the later stages in the development are different. One of the most noticeable differences is the position of the nucleus. Why it should remain in the centre of the cell in heart muscle, and in the voluntary muscle cell be situated at the periphery, is difficult to determine. Until more is known concerning the relation between the function of the cell protoplasm and that of the nucleus, this can only be the subject of hypothesis.

Since the beginning of the differentiation is the same in both heart muscle and voluntary muscle, the development of the power of contraction must run a somewhat similar course. If this be so, it is conceivable that contractions in definite directions begin when the irregular network of the primitive cell becomes made up of regular membranes at right angles to one another. When there is need of more perfect and stronger contractions, it is probable that the power for this is brought about by a strengthening of the network in the direction of the contractions. This strengthening takes place by an accumulation of the substance of the network, which gives rise to

fibril bundles. Why this should always take place first around the periphery of the cell is not clear. It is true, however, not only in the development of the heart muscle and the voluntary muscle cells, but also in the evolution of the heart muscle in lower animals. It is possible that there is a relation between this peripheral disposition of the fibril bundles and the spindle-like form of the cells. The fibril bundles, on account of their position, are curved in correspondence with the outline of the cell. On contraction, therefore, the pull is not only in the long axis of the cell, but also at an angle to this. Thus the cells acting together exert an influence on one another, which would not be the same if the fibril bundles, which are probably the chief agents in contraction, were situated in straight lines in the long axis of the cell. If this be so, the force which acts at an angle to the long axis of the cell must control the whole contraction, just as two muscles opposing one another make a more delicate mechanism than a single muscle. It is possible that this is of advantage in the early stages of the development. An hypothesis concerning such a subject must necessarily be vague and unsatisfactory. All that can be said with certainty is that there seems to be both in the histogenesis and comparative histology of the muscle cell a tendency for the fibril bundles to be formed first at the periphery of the cell. If the fibril bundles are the special contractile elements, it seems that it is of advantage to have the mechanisms for contraction as near the outer part of the cell as possible. The same thing is seen in the adult heart muscle fibre, for although nearly the whole cell is filled with fibril bundles, those at the periphery are many times as large as the ones which are nearer the centre.

III.—GROWTH OF THE HUMAN SARTORIUS MUSCLE.

In applying the process of development of the voluntary muscle fibre as described above, to explain a special muscle, I have endeavored to determine the relation between the growth of the muscle as a whole and the growth of the individual cells. The sartorius muscle was chosen for study because of its apparent simplicity of structure, and because its general characters in the adult vary within narrow limits. The fact that this definite and simple structure is developed gradually from a small group of embryonic cells, indicates that the growth takes place by a definite and simple process. In order to determine the exact nature of this process I have made estimations of the number of fibres to be found in cross-sections of the sartorius muscles taken from adults and from a series of human embryos.

Methods of Study.—Sections were taken from adult human sartorius muscles at the upper, middle, and lower thirds. Similar sections from the sartorius of a new-born babe were cut. Muscles were also used from a series of human embryos varying in length from 74 mm. (vertex to breech) to the stage shortly before birth. In these only the middle third was studied. Sections were cut in both celloidin and paraffin, celloidin being used mainly for the larger muscles. Various methods of staining were employed, but chiefly hæmatoxylin and eosin or safranin.

In obtaining the number of fibres found in a cross-section no effort was made to actually count them. All that was aimed at was to obtain as accurate an estimate as possible with methods which would entail the least number of errors. The most simple procedure seemed to be to compare the area occupied by the muscle-section as a whole and the average area occupied by a single fibre. This ratio must represent approximately the number of fibres. Thus the exact area of the whole cross-section was obtained and from this was subtracted the area of the connective tissue, giving the area of true muscle substance. The average area occupied by a single muscle fibre was then determined. The number representing the area of the muscle substance divided by that representing the area of one muscle fibre must be the number of fibres contained in the cross-section.

The sections of the larger muscles, adult and new-born, were projected on a screen with a projection lantern, and the outlines of the muscle and connective tissue carefully traced on a sheet of paper fastened to the screen. A slide ruled in millimeters was projected at the same time in order to obtain the exact magnification. This gave only the amount by which the length of a line was magnified, and in order to obtain the magnification in area this number was squared. A planimeter was used to determine in square millimeters the area of the muscle bundles in the tracing. This number divided by the magnification in area gave the actual area of the cross-section of the muscle.

For the smaller muscles a somewhat different method was employed. The sections were projected by means of a camera lucida and Leitz 3 objective, on a paper ruled in square millimeters. An exact tracing was taken as before of the muscle and the connective tissue in the section. At the same time a scale of hundredths of a millimeter was projected with the same power in order to obtain the magnification. The area of the tracing was got by counting the millimeter squares contained in it. At the edges only those squares were counted outside whose centre the line of tracing passed. The area of the connective tissue was similarly determined and subtracted from the area of the entire section. This gave the area of the muscle substance contained in the section. As a check on this the area of the muscle substance was directly counted. The actual area of the muscle was got as before by dividing the area of the muscle tracing by its magnification in area.

The actual area of one muscle fibre was determined by projecting the section upon a known ruled area by means of a camera lucida and a Leitz 7 objective. With a scale of hundredths of a millimeter a square was projected whose sides were .1 mm. in length. Its area therefore was .01 sq. mm. With the same power the muscle fibres were projected into this square and traced off. The fibres falling in the square were then counted and the number was divided into .01 sq. mm. This gave the average area occupied by one muscle fibre.

These two determinations were made for each section, so that all that was required to obtain an estimation of the number of fibres contained in the section was to divide the area of the muscle by that of the fibre.

Results of the Estimations.—The sections of the adult sartorius muscles were projected with a magnification of 14.5

diameters, that is, the area was magnified by 210.25. In the two muscles taken from the same subject the area in each case was greater in the middle third than in either the upper or lower third. In the right sartorius the area of the muscle tracing of the upper third was 19,880 sq. mm.; that of the middle third 24,490 sq. mm. and that of the lower third 18,390 sq. mm. In the left muscle the tracing of the muscle substance in the upper third contained 16,000 sq. mm., the middle third 22,760 sq. mm., and the lower third 18,250 sq. mm. In the new-born the muscle tracing of the upper third contained 2260 sq. mm., of the middle third 2430 sq. mm., and of the lower third 2040 sq. mm. These were all magnified to the same degree. This seems to show that the muscle substance in the sartorius is in the form of a spindle. There is a greater amount of muscle in the middle than at the two ends.

For comparison with the muscles of the embryos, only the middle of the sartorius was used in each case. The tracing of the middle third of the first adult sartorius contained, as mentioned above, 24,490 sq. mm. The magnification in area was 210.25, so that the actual area was 24,490 ÷ 210.25, or 116.48 sq. mm. The number of fibres in .25 sq. mm. of the muscle section was found to be 305, so that the area represented by one fibre .25 ÷ 305 = .0008196 sq. mm. The number of fibres, then, in the cross-section would be 116.48 divided by .0008196, which equals 142,118.

By a similar calculation the actual area of the section of the second adult sartorius muscle was found to be 108.252 sq. mm. The number of fibres in .25 sq. mm. was 315, and the area occupied by one fibre was .0007936 sq. mm. It follows from this that the number of fibres in the section is 108.252 ÷ .0007936, which equals 136,406. The number of fibres in the sartorius of the new-born babe was estimated by both the methods described. The results were slightly different. With a magnification of 14.5 diameters, and measured by the planimeter, the actual area was found to be 11.557 sq. mm. Magnified 14 diameters and projected on millimeter paper, the result was 12.316 sq. mm. The number of fibres in .01 sq. mm. was 98, and the area occupied by one fibre .000102 sq. mm. Then the number of fibres, according to one calculation, would be 113,304, and according to the other 120,745. This shows that the estimations are subject to an error of about 1 to 17, or somewhat less than 6 per cent.

Considering the individual variations, the number of fibres in the muscle of the new-born babe is approximately the same as that in the adult muscle. After birth, then, the growth in the number of fibres cannot be very great.

The largest human embryo studied was one which measured 200 mm. from vertex to breech. The actual area of muscle in the cross-section of the sartorius was 8.417 sq. mm. The area represented by one fibre was found to be .0000555 sq. mm. The number of fibres is 151,657. The greatness of this number can be accounted for only by supposing that the muscle would have been an unusually large one if it had become adult. It suggests, however, that there is little or no growth in the number of fibres after birth.

TABLE GIVING THE MEASUREMENTS, AND THE NUMBER OF FIBRES IN CROSS-SECTIONS, OF THE SARTORIUS MUSCLES OF THE FOETUS AND ADULT.

Number of Subject.	Length of Body.	Dimensions of Muscle in Millimeters.	Area of Muscle-tracing in Cross-Section.	Magnification in Areas.	Actual Area.	Number of Fibres in a known Area.	Area represented by one Fibre.	Number of Fibres.
Adult No. 74 (right)..	180 cm.	580x18x9	24490 sq. mm.	210.25	116.48 sq. mm.	305 in .25 sq. mm.	.0008196 sq. mm.	142118
Adult No. 74 (left)....	" "	580x21x8	22760 "	210.25	108.252 "	315 " " "	.0007936 "	136406
New-born.....	50 "	140x7	2430 "	210.25	11.557 "	98 " .01 "	.000102 "	113304
			2414 "	196	12.316 "			120745
	Vertex Breech. / Nape Breech.							
Embryo No. A.....	200 mm. / 130 mm.	52x6	1212 "	144	8.417 "	180 " " "	.0000555 "	151657
" No. 98.....	170 " / 106 "	42x6	1474 "	256	5.7578 "	223 " " "	.00004484 "	128408
" No. 65.....	130 " / 75 "	34x2.5	5901 "	5776	1.02164 "	442 " " "	.0000226 "	45205
" No. B.....	102 " / 65 "	28x3	6565 "	6400	1.02578 "	254 " " "	.00003937 "	26055
" No. 64.....	74 " / 46 "	19x1.5	4142 "	10816	.382858 "	170 " " "	.00005882 "	6509

The younger embryos were studied in the same way. One measured 170 mm. from vertex to breech. The actual area of muscle in the cross-section of the sartorius was 5.7578 sq. mm. The area occupied by one fibre was .00004484 sq. mm. The number of fibres, then, was 128,408. This number is approximately the same as that determined for the new-born and adult subjects. The muscles described thus far contain practically the same number of fibres in a cross-section. The differences can be accounted for by individual variation and by the nature of the estimation.

In the sartorius of an embryo 130 mm. from vertex to breech, the actual area of muscle in a cross-section was found to be 1.02164 sq. mm. The area occupied by one fibre was .0000226 sq. mm. The number of fibres, then, was 45,205. There is a very decided difference between this and the muscle last described. The number is less than one-third of that present in the adult muscles and in those of older embryos. It seems fair to conclude that in embryos between 130 mm. and 170 mm. in length the fibres found in the cross-section of the sartorius muscle increase in number as well as in size.

In the sartorius of an embryo 102 mm. from vertex to breech there was found a still smaller number of fibres. The actual area of muscle in a cross-section was 1.02578 sq. mm. and the area occupied by one fibre .00003937 sq .mm. The number of fibres, then, was 26,055. The difference between 45,205, which was the number found in the embryo 130 mm. long, and 26,055 is too great to be accounted for in any way but by an actual growth in number.

The sartorius from an embryo 74 mm. from vertex to breech gave in the cross-section an actual muscle area of .382858 sq. mm. The area represented by one fibre was .00005882 sq. mm. The number of fibres, then, was found to be only 6509. This number is less than one-quarter of that found in the embryo 102 mm. long, and about one-twentieth of the number in an adult.

These figures are put together in the preceding table. The adult muscles are placed at the top, and following these the embryonic muscles in the order of their measurements.

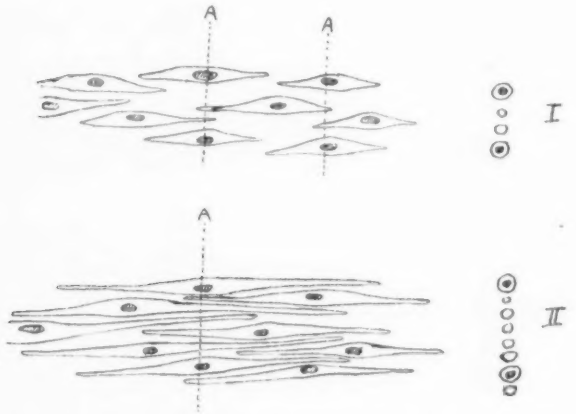

Fig. 6.—Diagram illustrating the Growth of Muscle. It shows the possible growth in the number of cells in a cross-section of a muscle, without a corresponding increase in the number of cells in the entire muscle. At the right the cells are represented as cross-sections taken in each case on the plane *A*.

It seems clear from this table that the growth in number of fibres, or at least the increase in the number found in a cross-section, takes place at a definite period. This increase in the number of fibres cut in any given cross-section might be brought about in two ways. There might be an actual increase in the number of fibres in the muscle as a whole, or there might be merely a growth in length of the fibres. This would cause them to grow past one another, so that a greater number would be cut in any one cross-section. This is illustrated in the diagram above, Fig. 6. In I and II there is the same number of fibres, but in II they are longer and have grown past one another. As a consequence the section A contains many more fibres in II than it does in I.

It is very possible that both of these processes go on at the same time. All that can be determined, with such methods as have been used here, is the growth in the number of fibres found in a cross-section of the muscle. This growth begins at a definite place in the development of the embryo. If the fibres ran the whole length of the muscle it would be a simple matter to determine the point at which the multiplication of the cells ceased; for then the number of fibres found in a cross-section would be the number contained in the whole muscle. In an embryo 140 mm. in length, however, longitudinal sections of the sartorius show that the fibres certainly do not run the whole length of the muscle. This is seen also in teased preparations. All that can be said, then, is that at a certain stage in the development, namely, in embryos between 130 and 170 mm. in length, the increase in the number of fibres found in a cross-section ceases. Since this increase is brought about by the two processes spoken of above, it is probable that the actual multiplication of cells ceases some time previous to this stage. If this be true, there are as many fibres present in the sartorius muscle of an embryo 170 mm. long as there are in the adult muscle. After this stage the growth in size of the muscle must be a growth in the size of the fibre.

It is to be emphasized, however, that the estimations given here are not of the number of fibres in the muscle as a whole. They are merely estimations of the number found in cross-sections, so that any suggestions as to the growth of the muscle as a whole are based on the supposition that the increase of the cells is uniform throughout the muscle. I have observed no indication whatever of special growing points in the sartorius muscle. In cross-sections the number of fibres is approximately the same in all parts of the muscle, although the tendons at each end make the number there somewhat less, as shown above. In the various embryos all the cells in any one section seem to be at the same stage of development. In longitudinal sections no growing points can be made out, and when karyokinetic figures are present they are not confined to any one part of the muscle. If the growth is proved to be uniform throughout the muscle, an increase in the number of the cells in the whole muscle must cause an increase in the number found in a cross-section. Indeed, the number found in a cross-section might increase after the actual number of fibres in the muscle had ceased to grow; for, as shown above, the cells in growing in length might pass one another and more of them would be cut in any section. If this be true, a small embryonic muscle, after a certain stage, becomes a large adult muscle, not by an increase in the number of cells, but by a growth in their size. This bears indirectly on other questions, and may prove of interest in connection with muscular hypertrophy. If the very enormous increase in size which the sartorius muscle undergoes during development can take place simply by a growth in the size of the individual cells, it is probable that such a small increase as is present in a muscle hypertrophied through exercise must be due to the same cause. It also seems probable that hypertrophy of the heart is due to growth in the size of the fibres rather than to an increase in their number. These are problems, however, which require special methods for their solution.

It is interesting to note the relation between the histogenesis of the cell and the growth in the number of cells in the sartorius. It will be seen on comparison of the figures given above, that the increase in the number of fibres ceases approximately when the fibre has become filled with fibril bundles, and the nuclei have become situated at the periphery of the

cell. In a human embryo 170 mm. long the muscle cells resemble the adult cells in every way except in size. This stage also marks the point at which the increase in the number of fibres found in a cross-section ceases. Embryos between 130 mm. and 170 mm. in length show the transition between the embryonic and adult types of muscle cells, and this is also the period at which the number of fibres stops growing. It will be remembered that in embryos 130 mm. in length the nucleus is centrally placed and vesicular in character, while in an embryo 170 mm. long the muscle cells contain only peripherally disposed nuclei. There is, possibly, a relation between the position of the nucleus and the power of the cells to produce new fibres.

The course of growth of the sartorius muscle may be epitomized somewhat as follows: At an early stage in the development, the cells are small and spindle-shaped, and scattered in loose bundles. At first there are no fibril bundles, and the nucleus is centrally placed. Subsequently the fibril bundles appear around the periphery of the cell. The cells multiply and increase in bulk until the embryo is between 130 mm. and 170 mm. in length from vertex to breech. At this stage the bundles of cells become more compact, and the cells themselves are filled with fibril bundles as in the adult. The nucleus is situated at the margin of the cell. The fibres now grow in length and thickness, but probably no longer increase in number. In embryos smaller than 170 mm. in length there is a regular increase in the number of fibres found in a cross-section. After this, however, the number remains approximately constant.

The study of the sartorius as the type of a simple muscle can only be a step towards the explanation of more complex muscles. When accurate methods of estimation have been employed in the study of muscles of more intricate character, and the results considered in connection with the process of histogenesis of the muscle fibre, a more definite idea of the growth of muscle in general may be arrived at.

FURTHER OBSERVATIONS ON THE CHEMICAL NATURE OF THE ACTIVE PRINCIPLE OF THE SUPRARENAL CAPSULE.

BY JOHN J. ABEL, M. D.

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In my first paper on the chemistry of the suprarenal capsules, in which I reported in detail on researches carried out with the help of Dr. A. C. Crawford, I was able to show that the blood-pressure raising constituent can be separated from aqueous extracts of the capsules in the form of a benzoate, and that this remarkable substance is not, as has been maintained, either pyrocatechin or an immediate derivative of it, and v. Fürth,* in an interesting paper published after, announces the same conclusion. We also gave as our opinion that this substance is to be classed with the alkaloids, founding this opinion on facts stated at length in our paper.

It is my purpose to give in the following brief paper an outline only of certain new observations made in the past year on this chromogenic substance or blood-pressure raising constituent.†

The extract used had been prepared with warm water slightly acidulated with sulphuric acid, and it was then concentrated in vacuo until the extract from 50 kg. of fresh suprarenals was reduced in volume to about 10 liters. This condensed extract was then heated to 80°, the coagulated proteids were filtered off and the clear filtrate benzoated in fractional portions. It was found to be unnecessary to remove the proteids entirely.

The crude, sticky mixture thus obtained, which consisted of the benzoates of our chromogen, of inosit, possibly also of carbohydrates, creatine and other substances, was then washed thoroughly with water and then dissolved as far as possible in warm glacial acetic acid. A considerable residue remained undissolved. The acetic acid solution was poured into much ether, and again a great deal of material was precipitated. The acid ether solution was first repeatedly shaken out with water, causing a further deposition of resinous matter, and then with a solution of sodium hydrate until all the acetic acid was removed and only a clear but slightly colored ether solution of a benzoate remained. These repeated washings caused copious deposits to fall out.

The ether solution was again washed with water and then once or twice with a 10 per cent. solution of sulphuric acid, followed with water. This washing with acid was now discontinued as it caused the benzoate of the chromogen to fall out in the form of a sticky resin.

It will be seen that by the above processes a number of foreign benzoates are removed; thus, the benzoate of inosit being insoluble in glacial acetic acid and that of grape sugar in ether.

When the benzoate of the chromogen had been treated as stated the ether was removed by distillation, and a yellowish, sticky benzoate remained which became brittle when allowed to dry in the air in thin layers. By boiling its alcoholic solution with animal charcoal, further purification was effected, so that when small quantities of this alcoholic solution were allowed to evaporate bunches of prismatic crystals were deposited. Many different solvents have been tried, but from none does it crystallize with enough difficulty to leave a mother-liquor.

Nevertheless, I have been able to learn something as to the

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*Hoppe-Seyler's Zeitschr. f. physiol. Chem., vol. 24, p. 142.

†It is a pleasant duty to acknowledge that this research would have been impossible but for the liberality of Messrs. P. D. Armour & Co., of Chicago, who have supplied me with large quantities of a concentrated aqueous extract of the suprarenals of the beef prepared according to my direction. My thanks are also due to Prof. A. G. Manns, chief chemist of the firm, for the care he has taken in preparing these solutions and for the interest he has taken in the scientific aspects of the subject.

composition and nature of the chromogen, the assumed blood-pressure raising constituent. In order to isolate this substance, the benzoate as obtained from the washed ether solution was decomposed with water in an autoclave under a pressure of 8–12 atmospheres. A clear, slightly straw-colored solution is thus obtained, which, when freed from benzoic acid and from a certain amount of a black resin which is deposited here as well as in other methods of decomposing the benzoate, gives all the well-known color and reduction tests of a fresh aqueous solution of the glands with one difference, which is that the addition of a little ammonia and iodine water no longer gives the characteristic rose-pink color, but instead, a vivid green. In all other respects the chromogen appears to be unaltered. A little ammonia, however, is set free during the hydrolytic decomposition just described, but whether this is derived from our substance or from some benzoate still contaminating the benzoate of the chromogen cannot as yet be stated.

When all the benzoic acid has been removed from the solution of the benzoyl product as taken from the autoclave, the cautious addition of very dilute ammonia, drop by drop, causes a copious precipitation of a substance which falls out in a flocculent precipitate much as does casein when precipitated from milk with acetic acid. The precipitate rapidly darkens and must be removed with the help of a suction filter as rapidly as possible.

It is washed with a little water, then with cold absolute alcohol and ether, and immediately ground up in agate mortars while it is still moist with ether. On drying it becomes a light grayish powder. This is the free chromogen with such slight modification as has occurred during the hydrolysis of its benzoate. When dry it is almost insoluble in water as also in a whole series of organic solvents; it is very soluble in warm dilute acids, in cold glacial acetic acid and in acetic anhydride. Dilute solutions in slightly acidulated water give an intense green color with ferric chloride or with ammonia, and they reduce ammoniacal silver solutions. Such solutions, exposed to the air, gradually deposit a brown precipitate, and this goes on until but little of the chromogen is left.

The behavior of the substance toward the halogens, which all precipitate it from its solutions, and toward the numerous alkaloidal reagents, I hope to report on at some future date. I shall only say here that a little of the dried chromogen obtained by breaking up the benzoyl product with acids as described in my first paper and which still gives the rose-pink color with ammonia and iodine water, strikes a rich plum color when treated with a drop of sulphuric acid or with Mandelin's reagent, reminding one of the effect of similar tests on strychnine. The chromogen as derived from its benzoate by hydrolysis in the autoclave does not give this color, but an olive-green followed by pink, which gives place to dirty hues.

Strong alkalies decompose the substance, boiling it with alcoholic solutions of potassium hydrate and chloroform brings out the nauseating odor of a carbylamine. On attempting to isolate this volatile substance by distillation, it was found to be decomposed, and on again treating the distillate with alcoholic potash and chloroform, the carbylamine was regenerated, thus showing that a primary amine had been split off when the chromogen was treated in this way.

SKATOL: A DECOMPOSITION PRODUCT OF THE CHROMOGEN.

On fusing the substance with powdered potassium hydrate and then diluting with water, the penetrating odor of skatol rises from the solution. When this solution is shaken out with ether and the ether allowed to evaporate, little globules remain having an intensely fœcal odor, and when these are dissolved in concentrated hydrochloric acid the solution at once takes on the fine characteristic pink color always seen when even small quantities of skatol are thus treated.

An alcoholic solution of these globules gives to a pine sliver, moistened with hydrochloric acid, a rich dark red color; a solution in benzol to which picric acid in benzol is added immediately deposits a picrate, not in crystals but in the form of reddish droplets, and an aqueous solution treated with sulphuric acid and potassium nitrite gives the whitish turbidity seen when skatol is similarly treated. Salkowski's reaction was also obtained, though imperfectly, as the production of intense colors in this test demands more substance than was left at my disposal.

The characteristic odor of this decomposition product, together with its chemical reactions, would make it appear that we have either skatol itself or one of the isomeric indols.

Some importance must be attached to this discovery, since, taken with the various reactions of the chromogen, the results of the elementary analyses and such facts as that dry distillation yields benzoic acid, amines, etc., and heating with zinc dust yields pyrol, it clearly enables us to classify the chromogen, in a preliminary way at least, among complex aromatic bases not very dissimilar from the alkaloids. The results of combustion analyses show that its empirical formula is $C_{17}H_{16}NO_4$, thus approaching in elementary composition some of the alkaloids.

The composition of pseudomorphine, for example, is represented by $C_{17}H_{19}NO_4$, that of cocaine by $C_{17}H_{21}NO_4$, that of sanguinarine by $C_{20}H_{15}NO_4$, and that of benzylidene collidine dicarboxyacid by $C_{17}H_{15}NO_4$, and among these alkaloids sanguinarine is noteworthy for its power to raise the blood pressure.*

In this connection, too, it is of interest to note that Stöhr† has shown that skatol is liberated when strychnine is heated with calcium oxide, and that Hoffmann and Königs‡ have obtained indol from tetrahydroquinoline by passing its vapor through a tube heated to redness.

ANALYTICAL RESULTS.

The results of the elementary analyses are as follows:

0.145 gm. of substance, dried in vacuo at 100° C., gave 0.3675 gm. CO_2 and 0.0684 of H_2O or 69.12% C and 5.24% H.

A second analysis made with 0.1862 gm. of substance, prepared at a different time and with slight modifications, gave 0.473 gm. of CO_2 and 0.0102 gm. of H_2O or 69.28% C and 6.09% H.

A nitrogen estimation, using substance prepared at the same time as that used in the second carbon and hydrogen analysis, gave the following results:

* H. Meyer, Arch. f. exp. Pathol. u. Pharmakol., XXIX, 426.
† Berichte d. Deutsch. chem. Gesellsch., vol. 20, p. 1108.
‡ Ibid., vol. 16, p. 738.

0.1784 gm. of substance gave 7.8 cc. of N at 21° C. and under a barometric pressure of 761 mm. of mercury. In this estimation, therefore, the N amounts to 5%.

Putting these results in tabular form, we have

	I.	II.
C =	69.12	69.28
H =	5.24	6.09
N =		5.00

Calculating for an empirical formula, we find that the expression $C_{17}H_{15}NO_4$ meets the requirements, since theory demands for

C 68.68
H 5.05
N 4.71

The agreement between the percentages demanded by this formula and the results obtained by analysis is as close as could be expected, since we are dealing with an amorphous substance and one in which the percentage of both H and N is very low.

In all of the above analyses a correction of 9.2 per cent. in the weight of substance given is made for ash. In spite of the fact that the benzoate itself is entirely free of ash, the amorphous chromogen obtained from it has carried down much mineral matter derived from the utensils used in the cleavage experiments and in subsequent manipulations.

The acetate of the new substance was also prepared and analyzed. The results thus far obtained are not fully in accord with the above formula, but this is due to the fact that the acetate decomposes during drying at 100° C. in vacuo. Acetic acid appears to be given off under these circumstances, and thus the C, H and N content is much changed from that required by the formula thus given. I do not doubt that when analyses are made with the avoidance of this loss the results will be concordant.

Not being able to repeat this part of the work at present, owing to lack of material, I here append the results of analyses made with an acetate which was constantly losing weight. The acetate was prepared by dissolving the free base in glacial acetic acid, and allowing this acid solution to flow in a thin stream into ether. The acetate is at once completely precipitated and may readily be collected, washed and dried. The percentages obtained on analyses were

C = 58.16
H = 5.82
N = 5.04

whereas the diacetate $C_{17}H_{15}NO_4(C_2H_4O_2)_2$ requires

C = 60.43
H = 5.51
N = 3.36

The analytic data for the above percentages of C, H and N are as follows:

0.153 gm. of acetate gave 0.3263 gm. of CO_2 and 0.0802 gm. of H_2O; 0.2046 gm. of the same material gave 9.1 cc. of N at 20.5° C. and under a barometric pressure of 754.6 mm. of mercury.

The method of preparation of the acetate does not tend to diminish the ash, and fusing the substance on platinum foil showed its presence in at least as large amounts as in the free base. In the absence of direct estimates for ash, it was thought fair to assume its presence to the extent of at least 10 per cent., and the weights here given have been corrected in accordance with this assumption.

I have already remarked that an analysis of the benzoate of the chromogen as thus far prepared showed it to contain C = 72.54%, H = 5.54%, N = 3.46%.

The analytic data are as follows:

0.2966 gm. of substance dried in vacuo at 80° C. gave 0.78895 gm. of CO_2 and 0.14785 gm. of H_2O. 0.29656 gm of the same material gave 8.7 cc. of N at 18.25° C. and under a barometric pressure of 760 mm. of mercury.

The monobenzoate of $C_{17}H_{15}NO_4$ is $C_{17}H_{14}NO_4.CO.C_6H_5$ and requires that

C = 71.82%
H = 4.74%
N = 3.49%

whereas our analysis gives

C = 72.54
H = 5.54
N = 3.46

This discrepancy in the carbon and hydrogen percentages is readily accounted for as the amorphous resinous benzoate analyzed is exceedingly difficult to dry to constancy of weight, and is, furthermore, perhaps not quite free from foreign benzoates. The results of analyses, nevertheless, point to the conclusion that we have the monobenzoate of the new base before us.

The above-named methods of isolating the active principle are far from being as satisfactory as could be desired. The resinous substance found in the autoclave on decomposing the benzoyl product always retains a considerable amount of the base. This may be extracted with dilute sulphuric acid and may then be precipitated with ammonia. This precipitation is, however, incomplete—a considerable amount of the base always remaining in solution. A considerable loss also occurs during the washing of the free base with water and alcohol, the latter agent especially dissolves considerable of the moist precipitate. The high ash content of the free base and of the acetate is also a most undesirable feature of the methods above described. Had there not been a tolerably fair agreement in the analytical results for the free base, its benzoate and acetate, with good reasons for the divergence in the case of the acetate, I should have hesitated to publish my results at this time.

I have lately found in sodium picrate a good agent for the complete precipitation of the base from its solutions in dilute mineral acids. The picrate is fairly soluble in a number of organic solvents, as, for example, alcohol, acetic ether and methylal, and may be precipitated from its solutions in these agents by the addition of much ether. On redissolving and reprecipitating a yellow picrate is obtained which leaves no ash when burned on platinum foil, and which, I believe, can be made to crystallize. It is my intention to give, in the near future, a more detailed description of the properties of this picrate with analyses and molecular weight determinations.

SUMMARY.

To summarize the results of this investigation in a few words: The active principle of the suprarenal capsule has been isolated in the form of a powder of a light gray to brownish color, whose percentage composition is expressed by the formula $C_{17}H_{15}NO_4$. A primary amine and a methylindol are easily split off from its molecule by treatment with powdered alkalies.

Should molecular weight determinations prove that the above formula correctly expresses the molecular weight of the new base, it will be seen that its molecule can contain

only one substituted benzene ring in addition to the nitrogenous complex of atoms from which the skatol is derived. Oxidation and substitution experiments are, however, still necessary before more definite statements can be made as to the constitution of this compound.

In its native state, as found in the suprarenal capsule, this substance differs by one chemical reaction only from its state as described in this paper. Chemically considered, the difference in composition between its native state and as here described must be very slight. And yet this difference which is just marked enough to give a greater stability to the substance is also great enough, apparently, to deprive it of its power to raise the blood-pressure, for, in the physiological experiments, thus far made, small quantities of the new base were found to be inactive in this respect.

I wish to express my thanks to my assistant, Dr. Walter Jones, for the valuable assistance rendered in making the analyses recorded in this paper.

THE LOBULE OF THE SPLEEN.

By Franklin P. Mall.

(*From the Anatomical Laboratory, Johns Hopkins University.*)

When the whole vascular system of the spleen is studied in connection with the trabecular system, it is found that the two together outline distinct masses of spleen pulp about one millimeter in diameter. These may easily be likened to the liver lobules, and for this reason I name them the lobules or the anatomical units of the spleen.

If a piece of fresh spleen is washed out by crushing it between the fingers in flowing water, it is found that the trabeculæ and veins outline spaces which were filled with pulp. They are best demonstrated by macerating the whole spleen in water at ordinary room temperature until the pulp is very soft. Then, by cutting off the small end of the organ, the debris may be washed out, leaving the capsule, larger veins and trabeculæ. A specimen obtained in this way may then be stained with acid fuchsin, washed with alcohol, distended and dried. Then with transmitted light the lobules are plainly seen as vesicles immediately below the capsule. By first injecting the spleen with either colored celloidin or agar-agar before macerating, the relation of the arteries and veins to the lobules can be determined. This is possible because neither the celloidin nor agar-agar is destroyed by the process of maceration. Thick sections made from such specimens may be immersed in xylol or mounted in Canada balsam.

It is found by studying numerous specimens of this sort, as well as those made by injecting cinnabar into the arteries and ultramarine blue into the veins, that the artery always penetrates the lobule and passes along its center, while the vein is intimately related to the trabeculæ and remains on the periphery of the lobule. In the case of the lobules lying immediately below the capsule, the artery enters the side as far away from the capsule as possible, as shown in the figure. The end of the lobule at which the artery enters I shall term the proximal side, while that opposite will be designated the distal side of the lobule. The deeper lobules of the spleen, then, have a distinct relation to the artery and not to the capsule. The Malpighian corpuscle usually lies in the proximal end of the lobule, but, in case it is very large, it may distend the lobule and cause it to bulge.

On an average there are 80,000 lobules in the spleen of a dog weighing 10 kg. In smaller spleens there may be as few as 25,000, while in larger spleens there may be 200,000. In all cases they are clustered together around the terminal branches of the artery in the same manner as the lobules of the lung are around the bronchus and the lobules of the liver around the hepatic vein. In order to understand the structure of the spleen it is necessary to study one lobule only, and for its anatomy the relations of the lobules to one another.

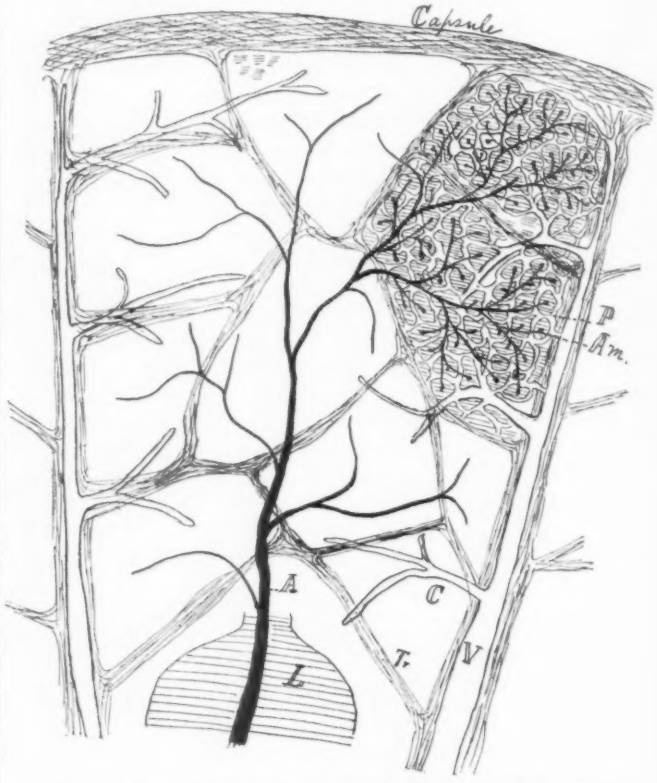

Fig. 1.—Diagram of the Lobule of the Spleen. *A*, artery in the centre of the lobule; *V*, interlobular vein within the interlobular trabeculæ; *Tr*, intralobular trabeculæ; *L*, Malpighian follicle; *C*, intralobular collecting vein; *P*, intralobular vein plexus which surrounds the pulp cords or histological units; *Am*, ampulla of Thoma.

The accompanying figure is a diagram of an average lobule drawn to scale. In no case can a picture like this be gotten from a single section, as the artery and two veins are never in the same plane. Moreover, the branches from the artery, as well as those from the vein, radiate from the main stem and pass in all directions. Practically all of the interlobular veins

are covered by interlobular trabeculæ, but there are numerous interlobular trabeculæ which are solid. In the periphery of each lobule there are three main interlobular trabeculæ, each of which sends three branches into each of the three surrounding lobules. The intralobular trabeculæ communicate with one another within the lobule, thereby dividing the lobule into about ten compartments. The relation of the veins to the lobule is much like that of the trabeculæ. In fact, it is the relation of the trabeculæ to the veins which makes the lobule. The large veins of the spleen cannot be said to lie within the trabeculæ, although their walls are thick, are continuous with the trabeculæ and give rise to them. The points which mark the separation of the smaller veins from the trabeculæ mark the boundary of the lobule (see diagram). As the venous branches leave the lobule they are at first independent of the intralobular trabeculæ, but near their exit they are related to them. The intralobular collecting veins also aid to divide the lobule into the ten parts, spoken of above. Of course the artery is distributed to the lobule from a direction opposite to that of the veins. The tendency is for veins and arteries of the same order to remain as far separated from one another as possible. The central artery of the lobule gives rise to about ten branches, each of which passes into one of the ten compartments of the lobule and through its centre. All of the above can be demonstrated best with granular injections, thick sections and low magnification.

If an interstitial injection of the spleen is made with an aqueous solution of Prussian blue, or if the blue is injected into the vein, it is found in either case that the venous plexus of the lobule is completely filled. This plexus is indicated in the figure giving its relation to the surrounding structures. It divides the spleen pulp into small areas or the histological units as I call them. In fact, however, these areas are not isolated, but communicate with one another as do the cavities of a sponge. Since the histological units run together to form cords of spleen tissue, I term them collectively pulp cords. Thick sections which leave the venous plexus intact show the optical section of the pulp cords or the histological units, while very thin sections cut the venous plexus and demonstrate the pulp cords. The terminal arteries ramify in the pulp cords and along their course, give off numerous small branches which end in a dilatation, the ampulla of Thoma. The beginning of the ampulla always lies in the centre of a pulp cord. As a rule a number of the minute branches arise from each terminal artery and radiate in all directions. I have been able to obtain complete injections of the vascular system of the spleen only after the organ has been distended to its maximum by ligating the vein half an hour before killing the animal or by making an artificial œdema with gelatin by injecting it into the veins. By both methods all the intercellular spaces within the pulp cords become enormously distended. In spleens prepared in either of the above ways the ampullæ and their communications with the veins may be filled by injecting an aqueous solution of Prussian blue into the artery. If carmine or some such fluid is used it will only add another color to the fluids in the pulp spaces. The blue, however, precipitates easily and with it, it is often easy to obtain complete injections. The specimen is made still better if the venous plexus is marked by injecting chrome yellow into the vein before injecting the blue into the artery. The gelatin-spleens are best cut on the freezing microtome and mounted in glycerine, as alcohol causes too much shrinkage of the gelatin. The injections show that the ampullæ have a tendency to communicate with ampullæ from neighboring arteries, while other branches communicate directly with the veins. Yet judging from the amount of extravasation which is always present the walls of the ampullæ must be very porous.

Carmine gelatin injected into either the artery or vein will cause an œdema of the pulp; in case it is injected into the artery it will ultimately run out of the vein, while when injected into the vein it will never run out of the artery. When cinnabar is injected into the artery, the greater part of it passes directly over into the vein, while a small portion of the granules pass into the tissues. When it is injected into the vein a considerable quantity passes into the intercellular spaces of the pulp cords, showing that the walls of the vein are pervious. Solutions of nitrate of silver injected into the artery show that the endothelial coat becomes incomplete at the beginning of the ampulla. The first two-thirds of the ampulla are lined with spindle-shaped cells lying upon a delicate framework of reticulum. Throughout the last third, at the junction with the vein, no cell boundaries can be demonstrated, nor can this portion of the ampulla be injected from the vein. In fact it appears as if this portion of the ampulla were cut up by fibrils of reticulum passing across it. Silver injected into the veins shows that the complete layer of cells ends at the point of junction of the intralobular plexus with the intralobular collecting veins. Throughout the plexus the cell walls are incomplete and the endothelial cells are spindle-shaped, the space between them being large enough to allow cinnabar granules to pass easily, ultramarine blue granules with difficulty, and chrome yellow granules not at all. The openings in the veins are largest in the neighborhood of the Malpighian follicles.

The reticulum extends throughout the lobule, supplies the framework for the ampullæ and the venous plexus, and is continuous with the reticulum of the lymph follicles surrounding the arteries. Its arrangement is such that an œdema distends the lumina of the veins out of proportion to those of the pulp spaces. The reticulum is very delicate and elastic. It can be stretched to double its length and when relaxed it will return to its former shape. It is easily destroyed with acid or with alkali, and is digested with pancreatin. This last reaction makes of it a new variety of reticulum. While this reticulum is so delicate and easily destroyed, the reticulum of the trabeculæ and capsule is most resistant. In fact, it is more resistant than that of the lymphatic gland or of the mucosa of the intestine. We have therefore within the spleen two extremes of reticulum, the most resistant and the least resistant.

The microscopic anatomy shows that the ampullæ and venous plexus have very porous walls which permit fluids to pass through with great ease and granules only with difficulty. In life the plasma constantly flows through the intercellular spaces of the pulp cords, while the blood corpuscles keep within fixed channels. Numerous physiological experiments which I have made corroborate this view.

A more detailed account of the facts enumerated above, together with illustrations, is being prepared for publication.

THE DEVELOPMENT OF THE BILE-CAPILLARIES AS REVEALED BY GOLGI'S METHOD.

By William F. Hendrickson.

(From the Anatomical Laboratory of the Johns Hopkins University.)

As the diverticula of epithelial cells grow from the mid-gut and surround the omphalo-mesenteric veins to form the liver there is from the first a duct present, the primitive bile-duct. In the further growth of the liver these diverticula anastomose again and again to form the main bulk of the liver of the embryo. To what extent bile-capillaries are present in these masses may in part be determined by treating the livers of small embryos with Golgi's method, and at the suggestion of Dr. Mall I have made numerous tests with this method to determine its value in the study of the development of the bile-capillaries.

The lobule is formed rather late in the development of the liver. In the younger livers the portal and hepatic veins have each for themselves their own regions of tissue about them, which in no way interlace. A later shifting and new formation of vessels is required before we have any indication of a lobule. Human embryos of the fourth week have already formed the main bile-ducts and hepatic artery along the branches of the portal vein, but I have been unable to demonstrate any bile-capillaries in human or in pig's livers from embryos less than 5 cm. long.

Although it is probable that the bile-capillaries are formed directly from the lumina of the liver sprouts from the mid-gut, yet it is impossible to prove this by means of Golgi preparations. The pictures obtained by this method are just the reverse of those expected when the question is considered from the standpoint of embryology. The first bile-capillaries stained by Golgi's method are found immediately about large portal branches in embryos 5 cm. long. From this stage on the pictures show a gradual spreading in both peripheral and central direction until bile-ducts are reached on the one hand and the intralobular plexus on the other. It may be that the Golgi method stains only those bile-capillaries which contain secretion.

My successful specimens were obtained from human as well as pig's embryos 5 cm. long, and longer. A great many specimens were made from pig's livers, repeated tests having been made to stain the capillaries in the livers of young embryos. The great quantity of these embryos at my disposal allowed me to make many Golgi specimens of livers in which the artery, the portal vein, or both had first been injected in order to determine the vessel about which the first capillaries appeared. In addition to this I made serial sections usually about 50 μ thick.

The first Golgi pictures are obtainable in the livers of pigs 5 cm. long (Fig. 1). Human embryos of the same size show a much more advanced network of bile-capillaries (Fig. 4). Yet repeated tests upon livers from pigs 5 cm. long always gave only a few capillaries in the immediate neighborhood of a large vein, which proved to be a branch of the portal vein. Specimens made by injecting either the portal vein or hepatic artery with a small quantity of Prussian blue before staining by Golgi's method always gave the same result, *i. e.* that the bile-capillaries are first stained in the immediate neighborhood of the branches of the portal vein.

Fig. 2 is from a pig's embryo 6 cm. long. It shows the bile-capillaries somewhat more extensive, they having encircled the portal branch. In an embryo a little larger, Fig. 3, the capillaries have grown still more, for those encircling different portal branches nearly meet. In addition to this extensive spreading each main bile-capillary has upon it many small side twigs. It appears as if the first meshes enclosed bile-capillaries are cut up by these side branches shooting across from one capillary to the other as the meshes enlarge by the multiplication of liver cells. Only in some way like this could the proper number of bile-capillaries keep pace with the growth of the liver.

The process described in livers of pig embryos up to 8 cm. long must have all preceded the condition found in the liver of a human embryo 5 cm. long, for in the pig's liver and the human liver in these two respective stages the degree of development of the bile-capillaries is much alike. A glance at Figs. 3 and 4 will readily show this. The network of the human liver, however, is much larger than that of the pig, but this seems to be the case throughout development.

Fig. 5 represents the extent of the bile-capillaries in a pig's embryo 15 cm. long. We find here that the bile-capillaries growing about one of the branches of the portal vein have become continuous with those about like branches in the neighborhood. The only indication left of the manner of growth of the bile-capillaries is seen in the relative size of their meshes. The meshes next to the veins are smaller than those situated farthest from the vessel about which the bile-capillaries arose. This figure illustrates again the progressive subdivision of the meshes formed by the bile-capillaries. The meshes near the veins are more dense than those farther distant, and this is easily understood since we know that those around the veins appeared first.

In the human embryo 10 cm. long the bile-capillaries are again as far advanced as those in pig's embryos 15 cm. long. Their relative size and extent are shown in Fig. 6, which may be compared with Fig. 4, taken from a human embryo 5 cm. long.

Fig. 7 is from a pig's embryo 21 cm. long, and Fig. 9 from a human fœtus at term. Both of these specimens show the network of capillaries distributed quite uniformly throughout sections, and at first thought it appears as if the growth of the capillaries was complete. But in the adult, both pig and human, the livers are considerably larger and the network is still smaller (Fig. 8).

If we had in the embryo's liver all the rudiments of the lobules of the adult liver it would not be so difficult to interpret these various pictures described above. In the livers of young embryos the portal and hepatic veins are in opposite ends of the liver, the portal being on the distal side and the hepatic on the proximal. When the liver is in this stage the

Fig. 1.—Pig, 5 cm. long.

Fig. 2.—Pig, 6 cm.

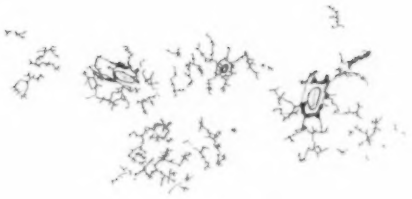

Fig. 3.—Pig, 8 cm.

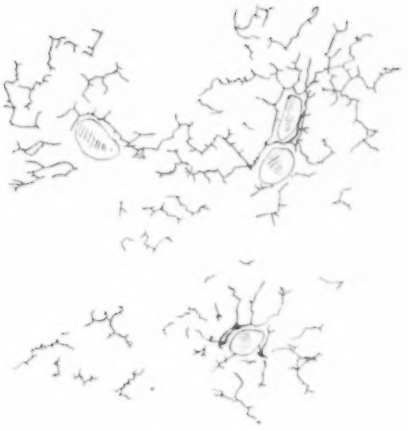

Fig. 4.—Human, 5 cm.

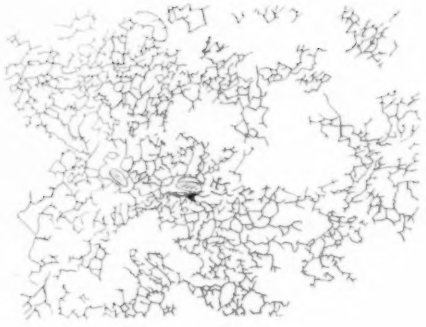

Fig. 5.—Pig, 15 cm.

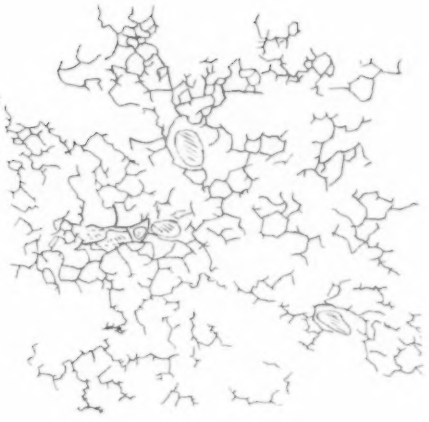

Fig. 6.—Human, 10 cm.

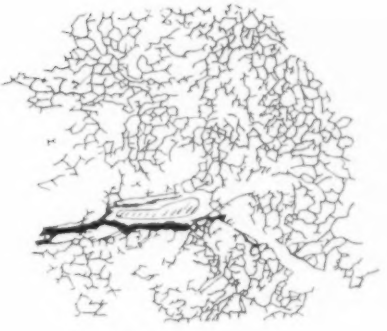

Fig. 7.—Pig, 21 cm.

Fig. 8.—Adult pig.

Fig. 9.—Human fœtus at term.

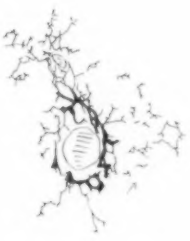

Fig. 10.—Pig, 8 cm.

Fig. 11.—Pig, 16 cm.

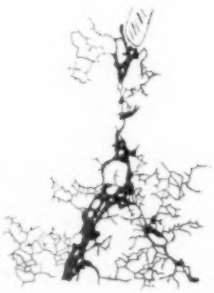

Fig. 12.—Pig, 16 cm.

Fig. 13.—Pig, 19 cm.

Fig. 14.—Pig, 16 cm.

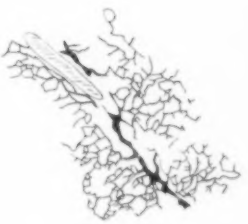

Fig. 15.—Pig, 20 cm.

Hendrickson, del.

bile-capillaries are first stained about the branches of the portal vein, although these veins cannot be called interlobular at this time. In the further growth of the vessels the hepatic veins invade the region occupied by the portal and vice versa. This process goes on, by what method we know not, until the lobules are finally formed. It is evident then that in the growth of the liver, as in bone, we must have destruction going on hand in hand with growth. Not only is this true during embryonic life, but Dr. Mall also informs me that a similar process is taking place in the lobule after it is formed. In this latter instance the liver lobule is constantly undergoing destruction in its centre and being regenerated at its periphery.

These facts complicate our problem considerably and make it practically impossible for us to interpret our specimens correctly. It appears, however, that in the further development of the liver the bile-ducts grow longer and longer at the expense of the bile-capillaries. At best the Golgi specimens indicate this, and, therefore, I can describe this process.

In the liver of a pig's embryo 8cm. long, the bile-capillaries immediately about the portal vein are somewhat more marked than those more distant. This is shown in transverse section in Fig. 10, and in longitudinal section in Fig. 11. This process is still more advanced in embryos 16 cm. long (Fig. 12), and in a measure we can speak of this large black capillary as a bile-duct. At first the dilatation is even and regular (Fig. 11), but soon it becomes irregular, the meshes become smaller and smaller until a number of capillaries together form a distinct bile-duct. The successive stages of this process are shown in Figs. 13, 14 and 15, and the completed duct is shown in Fig. 8. When the duct is completed the bile-capillaries communicate in great part only with its tip, and not all along its course as in the case of the younger ducts. This question, however, needs further investigation in normal as well as in diseased livers.

PLATE.

In all the figures the outlined and striated space is a branch of the portal vein. All the figures were drawn with the camera and are enlarged 53 times.

A STUDY OF THE MUSCULATURE OF THE ENTIRE EXTRA-HEPATIC BILIARY SYSTEM, INCLUDING THAT OF THE DUODENAL PORTION OF THE COMMON BILE-DUCT AND OF THE SPHINCTER.

BY WILLIAM F. HENDRICKSON.

(From the Anatomical Laboratory of the Johns Hopkins University.)

The idea that there is a sphincter muscle about the orifice of the ductus communis choledochus has been held since the time of Glisson. In the year 1887, however, Ruggero Oddi, an Italian, had cause to inquire more particularly into the subject. He found that no extended research had been made in this connection, and that the idea of a sphincter muscle of the common bile-duct was based for the most part on conjecture. Oddi accordingly undertook a careful study of the subject and used two methods: (1) maceration, (2) sectioning and microscopic examination.

With the maceration method he examined and described the sphincter muscle of the dog, which he regards as typical, and this description is followed by some observations regarding the differences observable in the sphincter muscle of the sheep, ox and hog. Oddi does not attempt to demonstrate the sphincter muscle in man by this method.

He studied also serial cross-sections of the duodenal portion of the common bile-duct of the dog and other animals, and describes them briefly.

The importance of such studies for the clinician interested in diseases of the biliary passages is obvious, and it is to be regretted that Oddi's material did not permit him to extend his studies to the bile-ducts of man. He states, it is true, that he has studied sections of the human bile-duct, and that he found sphincter fibres around the end of the bile-duct; otherwise his research deals entirely with tissues derived from animals.

In view of this fact a reworking of the subject with particular reference to human beings has seemed desirable, and the present work was therefore, at the suggestion of Dr. Lewellys F. Barker, undertaken. This report includes, it is believed, as full an account of the musculature of the biliary passages of man as the methods employed will permit of, and also contains references to a number of points hitherto unstudied in the structure of the biliary passages of animals.

I.—History.

II.—Methods employed.
- (a) Maceration with a mixture of nitric acid, glycerine and water.
- (b) Maceration with Ranvier's alcohol.
- (c) Stained celloidin and paraffin sections.

III.—The Musculature of the Biliary Passages in the Dog.
- (a) Gall-bladder.
- (b) Cystic duct.
- (c) Hepatic duct.
- (d) Common bile-duct.
- (e) Place of union of cystic, hepatic and common bile-ducts.
- (f) Duodenal portion of common bile-duct.

IV.—The Musculature of the Biliary Passages in the Rabbit.
- (a) Gall-bladder.
- (b) Cystic duct.
- (c) Hepatic duct.
- (d) Common bile-duct.

(e) Place of union of cystic, hepatic and common bile-ducts.
(f) Duodenal portion of common bile-duct.

V.—The Musculature of the Biliary Passages in Man.
(a) Gall-bladder.
(b) Cystic duct.
(c) Hepatic duct.
(d) Common bile-duct.
(e) Place of union of cystic, hepatic and common bile-ducts.
(f) Duodenal portion of common bile-duct.

VI.—Conclusions.

VII.—Index Lettering of the Figures.

I.—HISTORY.

For convenience the literature will be divided into two groups.

(*a*) That concerning the smooth muscle of the gall-bladder, cystic, hepatic and common bile-ducts.

(*b*) That on the structure of the duodenal portion of the common bile-duct.

ad (*a*) In 1761 Duverney* described the gall-bladder of man and divided its wall into four coats, the second coat being the muscular. The fibres which composed it were diversely arranged, some being longitudinal, others transverse or oblique. The fibres near the neck of the gall-bladder showed a circular disposition, and might be regarded as a sphincter.

In 1829, Wilson† declared that the presence of muscle fibres in the gall-bladder and the gross bile passages had not been demonstrated.

Koelliker‡ considered the musculature of the large bile-ducts to be but very little developed in man. He could not find a trace of muscle in the hepatic duct or in its branches. Bundles of smooth muscle were found, however, in the ductus choledochus and in the ductus cysticus, but not in sufficient quantity to justify the description of a muscular coat.

Only in the gall-bladder was a true muscle coat to be seen; here the muscle bundles crossed in all directions; still those running longitudinally and transversely predominated.

Tobien§ stated that muscle fibres are present in the human gall-bladder and that they run in all directions. The cystic duct, similar to the hepatic duct of man, contains no muscle. The presence of a ring of muscle fibres in the cystic duct near the gall-bladder was, however, confirmed by him. This ring of muscle is made up of contiguous muscle fibres, no connective tissue penetrating between them. He cites Glisson* and Duverney as supporters of the view that a sphincter of the gall-bladder exists, and names G. H. Meyer† as being of the opposite opinion.

Eberth‡ found in man and in the cat and dog, smooth muscle in the gall-bladder only. In each case the muscle fibres run for the most part in a circular direction; longitudinal and diagonal bundles are, however, present.

Luton§ describes the middle coat of the biliary passages as consisting of fibrous connective tissue, in which are some muscle fibres. In general the muscle fibres are not abundant, especially in the hepatic duct, cystic duct and common bile-duct. In the gall-bladder he finds a thin muscular coat, the fibres of which take two courses, viz. longitudinal and transverse.

MacAlister‖ believes that muscle fibres are present in what he calls the fibro muscular coat of the human gall-bladder. The muscle fibres run both circularly and longitudinally, but those of the latter direction constitute only about one-fourth of the whole number. In his description of the valvular folds of the cystic duct, he states that some muscle fibres are present in the bases of the upper valvular folds, but they do not seem to exist in the lower folds, *i. e.* those nearest the common bile-duct.

Paulet¶ found in the connective tissue of the biliary passages some contractile cells. The number present was not sufficient to form a continuous coat. Moreover, according to his statement the muscle fibres become less numerous as the calibre of the tube becomes larger. They are scanty in the cystic, hepatic and common bile-ducts of man. The gall-bladder also contains a certain number of smooth muscle cells, but never sufficient, at least in normal cases, to form a distinct coat.

According to Variot** the human gall-bladder contains a network of smooth muscle fibres, the interstices being filled with connective tissue. The common bile-duct exhibited in one case (human adult) discontinuous longitudinal muscular fasciculi; in another case (human adult) only a few circular bundles. In the dog, two superimposed strata of smooth muscle fibres were found which, very thick near the ampulla of Vater, became gradually thinner as the gall-bladder was approached. Between these strata of muscle is interposed a nervous apparatus analogous to that of the intestine.

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*Duverney (J.-G.) Oeuvres anatomiques. Paris, 1761, t. ii, p. 234.

†Wilson (C.) Observations on the mechanism of the biliary system. Edinb. M. & S. J., 1829, xxxi, 107–114.

‡Koelliker (A). Ztsch. f. wissensch. Zool. Leipz., 1848, S. 61–62.

§Tobien (A. I.) De glandularum ductibus efferentibus, ratione imprimis habita telæ muscularis. Dissertatio Inauguralis, Dorpat, 1853, S. 17.

*Glisson (Francis.) Anatomia hepatis; cui praemittuntur quaedam ad rem anatomicam universe spectantia. Et ad calcem operis subjiciuntur nonnulla de lymphæ ductibus nuper repertis. 16°. Hagæ, A. Leers, 1681.

†Meyer (G. H.) De musculis in ductibus efferentibus glandularum. Berl., 1837, p. 31.

‡Eberth (C. J.) Ztsch. f. wissensch. Zool., Bd. xii, 360, 1862.

§Luton (A.) Biliaires (voies). N. dict. de méd. et chir. prat., Par., 1866, v, 33–101.

‖MacAlister (A.) Contributions to the comparative anatomy and physiology of the gall-bladder. Med. Press and Circ., Dubl., 1867, n. s. iv, 129 and 150.

¶Paulet (V.) Biliaires (voies). Dictionnaire encyclopédique des sciences médicales. Paris, 1868, vol. ix, p. 295; 314.

**Variot (G.) Sur les nerfs des voies biliaires extra-hépatiques. Jour. de l'anat. et physiol., etc., Par., 1882, xviii, 600–610.

Sappey* in describing the structure of the human gall-bladder states that with the connective tissue composing the tunica conjunctivale and which forms a loose feltwork structure, are mixed some very delicate elastic fibres and some thin fasciculi of smooth muscle, scanty in man but more abundant in some mammals. The human cystic duct contains a plexiform arrangement of smooth muscle fibres. The ductus communis choledochus exhibits a structure identical with that of the other bile-ducts. In the hepatic ducts the diameter of which is 0.5 mm. or more he sees smooth muscle fibres which extend throughout the whole extent of the biliary passages. These fasciculi even in the large branches are very delicate and much separated. They exhibit a plexiform arrangement.

Cruveilhier† was not able to see the muscle fibres which other authors describe in the human gall-bladder, and ignored the possibility of the presence of muscle in the human cystic, hepatic and common bile-ducts.

Henle‡ believes the human gall-bladder contains smooth muscle fibres which interlace with one another. He finds no muscle in the human cystic, hepatic, and common bile-ducts, and considers the accumulation of ring-shaped muscle fibres described by Tobien as a sphincter vesicæ fellæ, to belong not so much to the cystic duct as to the neck of the gall-bladder. Henle experimented upon a beheaded man to determine the contractility of the biliary passages but with negative results.

Testut§ finds in the human gall-bladder smooth muscle fibres interlacing in all directions and bound together by connective tissue. In the cystic duct, only longitudinal muscle bundles are seen. The common bile-duct contains in its walls smooth muscle, well developed near the ampulla of Vater but on ascending the duct; this becomes less and less prominent until the muscle is even entirely absent at certain points in the duct.

Gegenbaur‖ states that in the connective tissue of all the human bile passages (cystic, hepatic and common bile-ducts) smooth muscle cells are to be found. In the wall of the gall-bladder they form a very thin coat, network like in character. Sometimes an indistinct longitudinal and circular coat can be made out.

Schäfer and Symington¶ state that the human gall-bladder contains plain muscle fibres which assume for the most part a longitudinal direction but some run transversely. They believe that the cystic and hepatic ducts also contain longitudinal and circular muscle fibres.

ad (*b*)—The presence of a sphincter muscle about the duodenal extremity of the common bile-duct was suspected as early as 1681. In that year Glisson** gave the following description:

"Quamprimum autem ductus hic communis utranque exteriorem intestini tunicam perrupit, adeo laxe eum interior tunica complectitur, ut digito huc illuc facillime dimoveri queat: hujusque mobilitatis ratione rem quamlibet ab intestino illapsuram arcet: quemadmodum id exploratu facile est, si modo, aperto intestino, acum aut specillum exiguum illac immittere coneris. Videbis enim, vario huc illuc subterfugio, spem omnem penetrationis eludere; nisi forte statim ipsum centrum illius, stylo tetigeris.

Præterea, ne quid ab intestino in ductum hunc illabatur, ipsa insertionis obliquitas in causa est: quic quid enim illo vorsum tendit, atque ingredi conatur, id simul eodem nisu interiores intestini tunicas versus exteriorem comprimit, ipsumque adeo aditum præcludit: idque eo magis, quo vis illata potentior fuerit.

Denique, regressus omnis in ductum communem præpeditur a fibris anularibus, quæ non modo orificium ipsum, sed & totum obliquum tractum obsident. Quemadmodum enim fibræ istæ anulares sese facile extendunt, quoties humor biliosus diutule repressus copiaque jam adauctus ad exitum properat; ita quoque, elapso semel superfluo humore illo, eædem penitus connivent, transitumque omnem impediunt, donec humoris plusculum denuo collectum fuerit, quod fores illarum effringat. Dari autem ejusmodi fibras anulares hinc constat: Si intestinum ex adverso orificii hujus aperueris, bilemque in illud digitorum opera adegeris, videbis statim ab exclusa bile orificium illud sponte sua denuo occludi; quod sane cirra ejusmodi fibrarum opem, fieri nequaquam posset. Similiter, si insertioni huic specillum indideris, idemque mox inde extraxeris; orificium jam dictum spontanes motu contrahi cernes. Ideoque crediderim aditum hunc eo nomine cum anisphinctere convenire, licet minore cum molimine clausura illic peragatur: nempe, si quando ab incumbente humore copioso molestia aliqua illata fuerit, mediantibus fibris hisce anularibus transitum ei concedit, denuoque in angustiam pristinam sese contrahit.

Ductus communis in ove aliter, quam in homine in intestinum inferitur. Quippe in illa, unicæ integræ spatio inter intestini tunicas prorepit, priusquam in illius cavum aperitur; tumque fissuram efformat, quæ per intestini longitudinem deducitur. Fissura haec laxa & spongiosa protuberantia, ab interiore intestini tunica enata, utrinque protegitur: adeo ut, si quidpiam altrinsecus in illam impingat, id eam protinus translabatur, hiatumque occludat. Ipsa tamen insertionis hujus obliquæ in ovibus longitudo, præcipue impedimento est, quo minus aliquid ab intestinis in ductum hunc communem regrediatur; quoniam enim orificium ejus in oblongam fissuram desinit, fibris ejusmodi anularibus nihil opus erat. Neque etiam insertio hæc in ovibus æque laxe huc illuc oberrat, atque in homine id fieri diximus: ac propterea, quoniam aliis jam dictis auxiliis destituitur, æquum erat, ut itineris longitudo, tunicarumque an invicem arcta compressio, illorum absentiam compensarent."

In 1869, Von Luschka* examined the intestinal portion of the common bile-duct of man and found a longitudinal open-

* Sappey (M. P. C.) Traité d'anatomie descriptive. Paris, 1889, t. iii, p 273.

† Cruveilhier (J.) Traité d'anatomie descriptive. 5 ed., 8°, Par., 1867–74.

‡ Henle (F. G. J.) Handbuch der systematischen Anatomie des Menschen. 8°. Braunschweig, 1856–73.

§ Testut (L.) Traité d'anatomie humaine, etc. Paris, 1889–91.

‖ Gegenbaur (C.) Lehrbuch der Anatomie des Menschen. 5. Aufl. 8°. Leipzig, 1892.

¶ Quain's Anatomy. 10. ed. London and New York, 1892.

** Op. cit.

* Von Luschka (H.) Die Pars intestinalis des gemeinsamen Gallenganges. Vrtljschr. f. d. prakt. Heilk., Prag., 1869, ciii, 86-100.

ing in the outer longitudinal coat, and a transverse opening in the inner circular muscular coat of the intestine which gave passage to the duodenal portion of the common bile-duct.

In 1887, R. Oddi* undertook to demonstrate the sphincter of the common bile-duct. He says: "I have found that no one has made a research upon this subject, although some, either by imagination or conjecture, have assumed the existence of such an arrangement."

Oddi employed in his investigation the macerating fluid proposed by Marcacci—a mixture of equal parts, by volume, of concentrated nitric acid, glycerine and water. The duodenal portion of the common bile-duct (of the dog, sheep, ox and hog) was examined with the best results. Oddi did not examine human specimens with this method. He mentions the following points as the result of a study of macerated specimens from animals belonging to different species. The course of the common bile-duct which runs across the intestinal tunic varies with the animal. Around the last part of the common bile-duct, almost in proximity with the mouth of the duct, he sees a muscular ring; this ring, after the removal of some delicate loops which run from its external surface to become lost in the muscle of the intestine, can be considered as independent.

Little by little, as the point of entrance of the common bile-duct into the intestinal wall is approached, the fusion of the circular fibres of the common bile-duct with the intestinal wall becomes more intimate, so that the common bile-duct cannot any longer be elevated. This may be due to the fact that of the circular fibres of the common bile-duct some run off to become implanted on the circular muscle of the intestine; like cords, fastened at the two poles of an oval, they go to become fixed at two firm points opposite one another in order to attain support. After these bonds have been cut the common bile-duct with its circular fibres can be isolated for some distance, up to the point where it plunges through the circular muscular fibres of the duodenum. Here the bile-duct raises the circular muscle fibres of the duodenum, forming a wedge-shaped opening. Oddi says it must be noted that in the animals examined by him, these fibres (sphincter fibres) did not appear always equally disposed, but necessarily assumed that form and disposition which could best adapt itself to the form and course of the common bile-duct in the intestine. Thus, in the sheep and the ox, where the common bile-duct runs parallel to the intestinal axis, they are hidden and parallel to the intestinal fibres; in the dog, in which case the common bile-duct runs obliquely to the axis of the intestine, they are oblique and less hidden; while in the hog, where the common bile-duct has a course like a "C", they are so strangely disposed as to be difficult to describe.

Oddi studied microscopically, sections cut transverse or perpendicular to the axis of the intestine of various animals at different levels. The following descriptions of the dog and sheep are given as typical. In a section taken at the point where the common bile-duct has just entered the muscular wall of the intestine, there is seen externally the stratum longitudinale of the muscular coat of the intestine, and just internal to this the stratum circulare which presents a buttonhole-like arrangement of its fibres through which the common bile-duct is seen to pass; the bile-duct is thus embraced by two muscular coats (formed by the buttonhole-like arrangement of the fibres of the stratum circulare), which reunite at its poles. Between the poles of the common bile-duct and the angle of reunion of the two muscular layers, there remains a triangular space, the base of which is formed by circular muscle fibres which both on the exterior and on the interior are inextricably mixed with the two circular muscular layers above mentioned. At the side of the circular muscle fibres just described are seen longitudinal fibres quite noticeable in section.

If the section be taken a little nearer the middle of the course of the common bile-duct, it is seen that the internal muscular layer has become thinner, while the external has acquired greater volume. Between the two layers the section of the duct can be seen, surrounded by a true muscular ring which is not intimately related with the two intestinal muscular layers. The muscular ring of the duct seems, in the section, to be entirely independent.

A section near the mouth of the common bile-duct shows that the division of the circular muscular layer of the intestine no longer exists—the ring described remains only in slight contact with the inner surface of the fibres of the stratum circulare of the intestinal muscular tunic. A continuation of the longitudinal fasciculi at the poles of the common bile-duct is also seen.

Oddi next proceeds to give some points distinguishing the animals examined from one another. A characteristic disposition of the muscle is, he says, proven for the rabbit. The muscular ring which envelops the common bile-duct appears in a section transverse or perpendicular to the long axis of the intestine. He emphasizes this fact, for it demonstrates, he thinks, the independence of these fibres from those of the intestine. In man, owing to the fineness of the muscle fibres, the disposition is not characteristic. Nevertheless, the circular as well as the longitudinal fibres (at the poles of the lumen of the common bile-duct) are very manifest. The circular fibres, however, cannot be followed for a great distance around, since, for the more part, they become lost in the connective tissue which supports the mucous membrane in its numerous anfractuosities. The fibres here mentioned have but little relation to the muscular layers of the intestine.

As to a special disposition of the muscular fibres at the mouth of the pancreatic duct, Oddi states that in the duodenum of a dog prepared by Marcacci's method of maceration, he was able to see at the mouth of the pancreatic duct (which is obliquely distant about two inches from the mouth of the common bile-duct) some special fibres disposed in a ring, very delicate and quite distinct from the intestinal muscular coats. This arrangement was confirmed by transverse and longitudinal sections taken at the mouth of the pancreatic duct.

II.—METHODS EMPLOYED.

In the present investigation three methods were employed to demonstrate the smooth muscle of the biliary passages.

* Oddi, R. Di una speciale disposizione a sfintere allo sbocco del coledoco. Ann. d. Univ. libera di Perugia. Fac. di med. e chir., 1886-7, ii, 249-264, 1 pl. Also, Reprint, Perugia, 1887.

(*a*) The most important of these, in some respects, is the method used by Marcacci* for demonstrating the musculature of the papilla mammæ. The method consists in macerating the tissue to be examined in a mixture of equal parts by volume of concentrated nitric acid, glycerine and water.

In applying it to the present study, the vertical portion of the duodenum was cut out and ligated at its two extremities. A cannula was introduced into the ductus choledochus and the above-mentioned mixture was injected into the intestine until its walls were well distended. The common bile-duct was next ligated and the entire specimen placed in a vessel full of the same macerating mixture. After a certain period of time the tissue was removed and placed in water. The intestine having been cut open on the side opposite the mouth of the common bile-duct, the mucous membrane was removed quite easily with forceps. The water was changed and the specimen allowed to remain thus for 24 hours. At the end of this time the specimen is ready for examination. The muscle fibres have the color and brilliancy of raw silk and, having absorbed water, stand out quite beautifully.

To demonstrate the muscle of the gall-bladder, cystic duct, hepatic duct and common bile-duct, the gall-bladder and hepatic duct were dissected from the liver; the hepatic duct was ligated and after ejecting the bile through the common bile-duct by pressure on the gall-bladder, the macerating mixture was injected up the common bile-duct until the walls of the gall-bladder were distended. The common bile-duct was then ligated and the whole mass placed in a vessel containing the same macerating mixture. The rest of the process is the same as for the duodenal specimen.

The period of maceration in nitric acid, glycerine and water has to be varied according to the delicacy of the specimen.

(*b*) Another method employed with advantage was that of maceration in Ranvier's alcohol. This method was found most useful in making permanent preparations of the gall-bladder. The gall-bladder, having been cut open, was allowed to macerate in Ranvier's alcohol for a week or ten days. The specimen was then removed and the epithelial cells brushed away with a stiff camel's hair brush. The serous coat and outer connective tissue coat were removed with forceps. The specimen was then stained with alum carmine or with hæmatoxylin and eosin and mounted in Canada balsam with the mucosal side down. This gives a bird's-eye view of the arrangement of the muscle in the wall of the gall-bladder.

(*c*) The third method employed was that of fixing, embedding, sectioning and staining the various parts. The specimens were fixed in absolute alcohol, formalin, or corrosive sublimate and imbedded in celloidin or paraffin. The principal stain used was that suggested by Van Gieson since the differentiation of minute quantities of smooth muscle from the surrounding connective tissue by this stain is quite exquisite. Other methods of staining were, however, employed for purposes of comparison.

* Marcacci (A). Il muscolo areolo-capezzolare. Gior. di R. Accad. di med. di Torino. 1883, 3. S., xxxi, 743–753. Also, Transl.: Arch. ital. de biol., Turin, 1883. iv, 292–254.

III.—THE MUSCULATURE OF THE BILIARY PASSAGES IN THE DOG.

(*a*) *Gall-bladder.*—Specimens macerated in a mixture of nitric acid, glycerine and water showed the arrangement of smooth muscle to be plexiform. The circular or transverse fibres are most numerous. The gall-bladders macerated in Ranvier's alcohol showed an arrangement exactly like the above. Longitudinal celloidin sections cut from the body of the gall-bladder, showed smooth muscle running in three directions, transverse, longitudinal and diagonal. Fig. 1.

Most of the muscle bundles run around the gall-bladder in a transverse direction, *i. e.* in a direction perpendicular to the long axis of the gall-bladder. The muscle bundles are not arranged in definite and regular coats; the transverse, longitudinal and diagonal bundles mingle without conformity to any rule. The muscle bundles are more or less separated from one another by a certain amount of connective tissue, but since the individual muscle bundles overlap, there are few if any places in this coat where muscle is entirely absent.

(*b*) *Cystic duct.*—Macerations in a mixture of nitric acid, glycerine and water revealed the presence of both transverse and longitudinal muscle fibres. In celloidin sections cut parallel to the long axis of the tube smooth muscle can be demonstrated running in three directions, transverse, longitudinal and diagonal. Fig. 2.

The absolute amount of transverse and longitudinal muscle is about equal. The diagonal muscle fibres are many fewer in number. The general arrangement of the smooth muscle bundles is plexiform. The connective tissue penetrates between the muscle bundles to a degree relatively greater than in the gall-bladder. Fig. 3 is taken from one of the valves of Heister. It is the largest fold found in this specimen and presents an arrangement of muscle which is much more accentuated in human specimens (*vide infra*). No such arrangement was found in the cystic duct of the rabbit.

In the cystic duct of the dog portions of the longitudinal muscle bundles curving around and running out into the valve can be made out. Other bundles of muscle, having origin apparently in the circular or transverse fibres of the cystic duct, run out into the valve. The report of the study of the Heisterian valves of human beings is accompanied by a detailed account of this arrangement.

(*c*) *Hepatic duct.*—Longitudinal muscle fibres were found in specimens macerated in a mixture of nitric acid, glycerine and water. Longitudinal sections of the hepatic duct showed only longitudinal fibres. Fig. 4. The fibres are but few in number and the disposition of the muscle is such that there can be no talk of a continuous coat.

(*d*) *Common bile-duct.*—Macerations in a mixture of nitric acid, glycerine and water showed a few longitudinal muscle fibres. Longitudinal celloidin sections showed smooth muscle running in three directions, longitudinal, transverse and diagonal. Fig. 5. The longitudinal bundles are most numerous, the transverse bundles next in number, the diagonal bundles being least numerous. The muscle fibres do not form a complete coat; they are found scattered amongst much connective tissue.

(*e*) At the place of *union of the cystic*, hepatic and common

bile-ducts, no extraordinary muscular arrangement was seen. Each duct preserved its normal structure, the wall of each gradually merging into that of the others.

(*f*) *Duodenal portion of the common bile-duct.*—That portion of the duodenum which contains the duodenal papilla having been macerated in a mixture of nitric acid, glycerine and water as described above, was examined in the following manner: The intestine was cut along its longitudinal axis on the side opposite the duodenal papilla and laid open. The mucous membrane was removed and with it the muscularis mucosa. The appearances at this stage are represented in Fig. 6.

From the point where the common bile-duct enters the intestine *A* to the point *R*, the muscle fibres of the inner circular muscular coat of the intestine are seen to pass over the common bile-duct. From the point *R*, to the point *C*, an irregular arrangement of muscle bundles is seen to exist. This arrangement resembles in shape more or less that of a mark of interrogation placed in a horizontal position. The structure has its origin (1) partly in the fibres of the inner circular muscular coat of the intestine, (2) partly in fibres which lie under the inner circular muscular coat and which arise from the median line of the bile-duct and (3) partly from the ring of muscle surrounding the mouth of the bile-duct. The fibres after this origin run forward (*i. e.* towards the lower end of the duodenum) and, passing under the fibres of the inner circular muscular coat of the intestine, blend with the fibres of the outer longitudinal muscular coat.

Out of eight specimens I found no two cases in which this irregular arrangement was alike. A description of the mode of origin and termination of these muscle bundles is accordingly of but little value, although an exact determination was made in each case.

Continuing from the point *C* to the mouth of the common bile-duct *M*, one can see muscle fibres running around the end of the common bile-duct. A careful examination of this region shows that a complete ring of muscle surrounds the mouth of the common bile-duct. At the same time, close observation reveals a certain number of muscle fibres running off from the two sides of this annulus of muscle. These latter are in reality part of the ring of muscle and after separating from the ring at its sides bend abruptly forward, *i. e.* towards the lower end of the duodenum. This ring of muscle with the lateral muscle bundles arising from it constitutes the sphincter of the ductus communis choledochus.

In Fig. 6 the muscle bundle seen coming off from the non-pancreatic* side (see *X*) of the annulus of muscle corresponds with the arrangement usually found. At first sight there seems to be no corresponding bundle for the other side (*i. e.* pancreatic side) of the muscle ring. It will be remembered, however, that the structure similar to a mark of interrogation had its origin in part in some fibres of the muscle ring about the mouth of the common bile-duct. These fibres of origin, in this case, take the place of the muscle bundle which runs off at the pancreatic side of the muscle ring. The fasciculus on the pancreatic side of the muscle ring must terminate, after running forward a short distance, as described above in connection with the termination of the structure resembling a mark of interrogation—by passing under the fibres of the inner circular muscular coat of the intestine and blending with the fibres of the outer longitudinal coat. The fasciculus on the non-pancreatic side of the muscle ring, after running forward a short distance, curves slightly to the pancreatic side and finally terminates by mixing superficially with the fibres of the inner circular muscular coat of the intestine. The manner of termination of these lateral fasciculi of the annulus about the mouth of the common bile-duct varies somewhat. They end:

(a) By mixing superficially with the fibres of the inner circular muscular coat.

(b) By passing more or less abruptly under the fibres of the inner circular muscular coat and becoming lost among the fibres of the outer longitudinal coat.

(c) One lateral fasciculus may resemble description given under (a); the other may resemble that given under (b). An illustration of this is given in Fig. 6.

After this preliminary study an incision was next made along the median line of the common bile-duct extending from the point *A* to the point *R*. The fibres of the inner circular muscular coat of the intestine were then peeled off the bile-duct on both sides of the incision. The structure shown in Fig. 7 was revealed. Along the median line of the common bile-duct, a number of muscle fasciculi can be seen to arise. From this origin the muscle bundles run down and forward (towards the lower end of duodenum) over both sides of the common bile-duct. As the fibres on either side of the common bile-duct run forward they unite, forming a relatively large bundle of muscle on each side of the bile-duct and in direct contact with it.

The manner of termination of these bundles of muscles (running parallel with the bile-duct) varies somewhat. They end:

(a) By running forward and around under the ampulla of Vater, becoming continuous with fibres of the inner circular muscular coat of the intestine.

(b) By running forward, turning away from the bile-duct and blending with fibres of the inner circular muscular coat of the intestine.

(c) By running forward, passing under the annulus of muscle about the mouth of the common bile-duct and becoming lost among these fibres.

(d) One side ends according to (b); the other side according to (c).

The mode of termination in Fig. 7 corresponds to that described under (c).

At the point *O*, Fig. 7, some fibres of the inner circular muscular coat bend around the common bile-duct forming a U-shaped curve. This is the place of entrance of the common bile-duct into the muscle of the inner circular muscular coat of the intestine.

The common bile-duct is finally teased completely away and the muscle fibres of the inner circular muscle coat are revealed. These muscle fibres are found to be present from the point *A* to the point *M*, Fig. 6. It will be remembered that fibres of

* The terms non-pancreatic and pancreatic are used here to discriminate between the two sides of the bile-duct. The pancreatic side is so called because the common bile-duct is usually joined on this side by the duct of Wirsung.

the inner circular muscular coat pass over the common bile-duct from the point *A* to the point *R*. Removal of the remaining fibres of the inner circular muscular coat discovers the outer longitudinal muscle coat of the intestine. In Fig. 8, the point *F* represents the arrangement of the fibres of the outer longitudinal muscle coat of the intestine at the place of entrance of the common bile-duct into the intestinal wall.

In addition to this general description the following points deserve to be mentioned. In some specimens at the pancreatic side of the mouth of the common bile-duct additional muscle bundles more or less involved with some already described can be made out. The resulting structure suggests a *point d'appui*. One never sees such a *point d'appui* developed on the non-pancreatic side.

In all cases the course of the common bile-duct through the wall of the duodenum is slightly oblique with reference to the inner circular muscle coat of the intestine; in most cases the course is also slightly curved—the convex side being the pancreatic side of the common bile-duct.

The Duct of Wirsung.—Speaking relatively, the duct of Wirsung was found in many cases to run among the muscle fibres of the *point d'appui* situated at the pancreatic side of the mouth of the common bile-duct. The duct of Wirsung joins the common bile-duct at its extreme end; the pancreatic and common bile-duct opening side by side. The annulus of muscle fibres about the mouth of the common bile-duct accordingly also embraces the mouth of the duct of Wirsung.

In Fig. 8, point *W*, the arrangement of the outer longitudinal muscle coat of the intestine at the point of entrance of the duct of Wirsung into the intestinal wall is illustrated.

A study of serial cross-sections of the duodenal portion of the dog's common bile-duct.—Two sets of serial sections were prepared and examined. The specimens were stained in bulk with borax carmine and embedded in paraffin. The following drawings are taken from sections at different points in the course of the common bile-duct through the intestinal wall. They begin near the duodenal papilla and pass back towards the point of entrance of the duct into the intestinal wall. (Figs. 9 to 13).

Fig. 9 is made from a cross-section taken through the duct of Wirsung and the common bile-duct near their junction. Most interest attaches to the appearances in the submucosa. Here are to be seen two openings with irregular contours. The one to the right—the larger—is the lumen of the ductus communis choledochus. The other is the lumen of the duct of Wirsung. Surrounding these lumina, so as to embrace them, are bundles of smooth muscle. The figure shows one muscle bundle traversing the space between the two lumina and connected above and below with other muscle bundles in such manner as to form a double ring of muscle embracing the two ducts. The ring of muscle here shown corresponds to the muscle ring about the mouth of common bile-duct found in macerated specimens. Examination of second set of serial sections in this region showed the muscle ring embracing both the common bile-duct and the duct of Wirsung, but in this instance no distinct bundle of muscle could be seen traversing the space between the two lumina. Apparently no one has suspected, up to the present time, the existence of this double muscle ring embracing the mouths of the common bile-duct and the duct of Wirsung.

On both sides of this double ring of muscle one can make out muscle bundles cut transversely. In two or three places the bundles of the muscle ring are connected with these transversely cut fibres. These bundles (transversely cut) as well as others seen below lying on the inner surface of the inner circular muscular coat of the intestine, represent sections of those lateral fasciculi which in macerated specimens are seen to have origin in the ring of muscle about the mouth of the common bile-duct and to bend around and run down in the duodenum (see *X*). Other sections show these lateral fasciculi terminating by mixing superficially with the muscle fibres of the inner circular muscular coat. It is to be noted that the lumen of the common bile-duct is partially filled with folds of mucous membrane at this point.

Fig. 10 is taken at a point further away from the mouth of the common bile-duct. In this section only one lumen is present, that of the common bile-duct. The lateral fasciculi which have origin in the ring of muscle about the mouth of the common bile-duct, and which bend around and run down the duodenum are, however, shown here quite well. The mass of muscle to which the lateral fasciculus runs (on the left) probably represents the *point d'appui* noted in the macerated specimens.

Fig. 11 is taken at a point about midway in the course of the common bile-duct through the intestinal wall. The structures show the division of the inner circular muscular coat of the intestine. Part passes over and part passes under the common bile-duct. Where the two parts of the inner circular muscular coat unite on either side of the common bile-duct to form the complete inner circular muscular coat again, muscle fibres can be seen running from the upper to the lower part. This occurs on both sides, and there is, therefore, a complete ring of muscle around the duct. This arrangement must not, however, be regarded as perfectly symmetrical. Furthermore, some sections in this region show a simple decussation of fibres of the upper division with fibres of the lower division of the inner circular muscular coat. This latter arrangement (decussation on both sides of the common bile-duct) seems to hold entirely for the second set of serial sections. On both sides of the lumen of the common bile-duct, muscle bundles in transverse section are seen. These represent those bundles of muscle which have origin in the median line of the common bile-duct and afterwards run forward parallel with the long axis of the tube (see *N*).

Fig. 12 shows those muscle bundles which arise in the median line of the common bile-duct. They are seen here only on the right, running down over the side of the bile-duct (see *N*); it should be noted, however, that this arrangement is bilateral. The bundles of muscle cut transversely represent those muscle bundles which run forward, parallel with the common bile-duct, after taking their origin in the median line of the bile-duct.

Fig. 13 is taken at a point where the bile-duct has almost left the intestinal wall. The inner circular muscular coat passes entirely over the common bile-duct at this point. At the sides are seen large masses of longitudinal muscle fibres. These are the fibres of the outer longitudinal muscle coat which

have been pushed aside to allow passage to the common bile-duct.

IV.—THE MUSCULATURE OF THE BILIARY PASSAGES IN THE RABBIT.

(*a*) *Gall-bladder.*—The nitric acid, glycerine and water macerations show only transverse muscle fibres.

Specimens macerated in Ranvier's alcohol, and longitudinal celloidin sections reveal a muscular arrangement practically identical with that found in the dog. There seems, however, to be relatively more muscle in the gall-bladder of the rabbit than in that of the dog.

(*b*) *Cystic duct.*—Only transverse muscle fibres are seen in specimens macerated with nitric acid, glycerine and water. Longitudinal celloidin sections show the absolute amount of smooth muscle in the walls of the cystic duct to be small, and that the muscle fibres run in three directions, longitudinal, transverse and diagonal. The transverse muscle fibres are most numerous, the longitudinal fibres next in number and the diagonal fibres least of all. Connective tissue penetrates between the muscle bundles to a relatively greater degree than in the gall-bladder.

(*c*) *Hepatic duct.*—No muscle fibres were found in macerations with nitric acid, glycerine and water. Longitudinal celloidin sections showed a very small amount of muscle. The muscle fibres follow three directions, longitudinal, transverse and diagonal. The longitudinal fibres are most numerous. The transverse and diagonal fibres are about equal in number but there are very few of either variety. There is much connective tissue here between the muscle.

(*d*) *Common bile-duct.*—Muscle fibres could not be detected in nitric acid, glycerine and water macerations. Longitudinal celloidin sections show longitudinal and transverse muscle fibres. The former are much more numerous than the latter. The absolute amount of muscle present in the walls of the common bile-duct is, however, very small.

(*e*) No extraordinary muscular arrangement was found at the place of union of the hepatic and cystic ducts with the common bile-duct.

(*f*) The *rabbit's duodenum* was macerated in a mixture of nitric acid, glycerine and water. After the mucous membrane had been removed the structure represented by Fig. 14 was found. The course of the common bile-duct through the intestinal wall is parallel to that of the fibres of the inner circular muscular coat. This is just the reverse of what is found in the dog. At the first glance, one can see that the greater part of the duodenal portion of the common bile-duct is covered with muscle fibres of the inner circular muscular coat.

Some of these fibres of the inner circular muscular coat run up on the common bile-duct (see *A*), continue for some distance and terminate abruptly near the orifice of the duct (see *R*). Other fibres of the inner circular muscular coat run up on the duct, continue forward a short distance, but finally bend, some to one side, others to the opposite side (see *C*) and running down over the side of the duct, become continuous with the fibres of the inner circular muscular coat. The presence of some fibres of the inner circular muscular coat just under the ampulla of Vater is to be noted (see *CS*).

Fig. 14 also shows a sphincter muscle about the orifice of the common bile-duct (see *S*). This sphincter is composed of a muscular ring which surrounds the orifice of the duct. Some fibres instead of running completely around the orifice, run off at the side of the ring and bending forward become continuous with the fibres of the inner circular muscular coat.

The fibres of the inner circular muscular coat were next removed (except at *OS*). The arrangement seen is represented in Fig. 15. The common bile-duct is seen penetrating the outer longitudinal muscular coat. The outer longitudinal muscle at the point of entrance of the common bile-duct (see *A*) covers some muscle fibres which run around the common bile-duct embracing it. Immediately after penetrating the outer longitudinal muscular coat the bile-duct can be seen to be encircled with smooth muscle. Those muscle fibres nearest the point of entrance of the common bile-duct, run around or encircle the bile-duct without bending forward (see *IR*), but as the orifice of the duct is approached the muscle fibres which embrace the bile-duct, after running down over the side of the duct, bend forward more and more.

Thus it will be seen that in all cases, the muscle fibres described embrace the duct but with the difference pointed out above, namely, that those fibres nearest the point of entrance of the common bile-duct do not bend forward as they pass under the common bile-duct, while those nearer the orifice of the bile-duct do bend forward as they pass under it. All the muscle fibres just mentioned doubtless have a sphincter function, but if we regard the sphincter muscle of the dog we will find it homologous with the sphincter fibres *S* of the rabbit. Therefore, the rabbit has not only a sphincter similar to that of the dog, but it possesses also other fibres which subserve in all probability the same or a similar function.

The muscle fibres encircling the common bile-duct were now cut along the long axis of the duct. The mucous membrane of the duct was removed and an arrangement represented in Fig. 16 was found. At this point it is well to recall that the fibres marked *CS* in both Fig. 15 and Fig. 16 are those fibres of the inner circular muscular coat which lie immediately in front of and also under the ampulla. These muscle fibres (see Fig. 16, *CS*) run under the ampulla and there decussate irregularly, so that the fibres of the one side pass to the other side, and then curving upward and backward around the common bile-duct, embrace it. Here is seen the origin or termination of those muscle fibres which embrace the common bile-duct and bend forward as they pass under the bile-duct. Passing from this place of decussation, back toward the point of entrance of the common bile-duct into the intestinal wall, one finds the continuation of those muscle fibres which simply embrace the duct without bending forward as they pass under it (see Fig. 16, *IR*).

The muscle fibres of the outer longitudinal muscular coat, which lie in front of the ampulla and under the fibres marked *CS* have no connection with the muscular arrangement of the duodenal portion of the common bile-duct. Further back, however, near the decussation of the fibres *CS*, the fibres of the outer longitudinal muscle coat seem to be more or less involved in the general decussation. Some of the fibres of the outer longitudinal muscle coat run up to the side of the bile-

duct, then bend around and run forward on it and at its side toward the ampulla. Others, when they reach the side of the duct, plunge inward and mingle with those bundles which embrace the common bile-duct.

Serial cross-sections of the duodenal portion of the common bile-duct of the rabbit.—Two sets of serial sections were prepared and examined. The principal points of interest are presented in the following cuts which are taken at different levels in the duodenal portion of the common bile-duct. The first figure corresponds to a section taken nearest the orifice of the common bile-duct, the others are taken at successively different levels throughout the length of the duct.

In Fig. 17, at first glance, the course of the common bile-duct in the intestinal wall is seen to be parallel to the inner circular muscular fibres. The duct is situated in the submucosa of the intestine, and is seen to be surrounded by muscle bundles. The smooth muscle embraces the common bile-duct, but on each side of it some muscle fibres, instead of running under the duct, turn forward and the cross-sections of the individual smooth muscle cells indicate the fact that they have continued as a part of the fibres of the inner circular muscular coat (see *X*). Between the mucous membrane of the common bile-duct and the inner circular muscular coat of the intestine are seen muscle bundles which run transverse to the course of the common bile-duct. These fibres correspond to that portion of the sphincter which runs under the common bile-duct. Comparison shows that the inner circular muscular coat (see *CS*) has lost few if any muscle fibres at this point. This is a fact which will have more importance in connection with the decussation of the fibres of the inner circular muscular coat. It should be noted that the fibres marked *CS* correspond to those marked *CS* in the macerated specimen. At this level of the common bile-duct the lumen is occupied to a considerable extent by folds of mucous membrane.

Fig. 18 has been taken at a level in the duodenal portion of the common bile-duct, further from the orifice than Fig. 17. The structures to be noted have passed from the submucosa into the tunica muscularis of the intestine. The large lumen of the common bile-duct is conspicuous (see *B*) and to the right, the first indication of the duct of Wirsung is met with. If we begin the description at the extreme left of the figure, just beneath the submucosa are to be seen a large number of muscle fibres in cross-section (see *CI*). These are present, but in diminished number throughout more than one-half the breadth of the section. These fibres belong to the inner circular muscular coat of the intestine which at this point does not quite cover the bile-duct.

Toward the extreme right are seen large bundles of transversely cut muscle fibres (see *CI*). Running to join these last named bundles, are muscle fibres cut diagonally and longitudinally. The longitudinally cut muscle fibres apparently arise from the outer longitudinal muscle coat of the intestine and running over the common bile-duct finally bend around and become continuous with the transversely cut inner circular muscular fibres *CI*. If we again examine the extreme left of the figure, there are to be seen fibres cut longitudinally (see *LI*) immediately under the inner circular muscle coat. These represent the outer longitudinal muscular coat. In this particular section there is a division of the fibres of the outer longitudinal muscular coat. Some pass over the duct and then bend around as described above to become continuous further forward with the inner circular muscle coat. Others run as if to pass under the bile-duct but suddenly terminate. In their place one sees transversely cut muscle fibres which extend for a considerable distance to the right and then suddenly stop (see *LF*). Where these fibres (*LF*) stop we find longitudinally cut muscle which represents the outer longitudinal muscle coat of the intestine (see *LI*). The explanation of the structures last mentioned is probably to be found in the circumstance that the muscle fibres of the outer longitudinal muscular coat on either side of the long axis of the common bile-duct bend around and, converging, run forward in the direction of the ampulla of Vater. The fibres marked *LF* represent those muscle bundles which run forward. The transversely cut muscle fibres marked *CS* represent fibres of the inner circular muscle coat. These are the continuation of the fibres marked *CS* in Fig. 17 and correspond to the *CS* fibres of the macerated specimen. At this level the decussation of the inner circular muscle fibres as described in the macerated specimen ought to be seen, and as a matter of fact this decussation corresponds to those muscle bundles of the figure which have not already been described. They run up on the right as diagonally cut muscle. The segments of diagonally cut muscle show that successive bundles have been cut. Running under the bile-duct is another large muscle bundle. To the left of the bile-duct are still other bundles of diagonally cut muscle. I believe that all these bundles come from the *CS* fibres of Fig. 17 and that their particular arrangement is due to the decussation and subsequent embracing of the common bile-duct by them. This arrangement will be better understood by referring to the macerated specimen. This series of sections did not show muscle running between the lumen of the common bile-duct and the lumen of the duct of Wirsung, to form a double sphincter. Examination of the second set of serial sections, however, at about the same level as that represented by Fig. 18, proved this structure to be present. Here were found muscle bundles arising on the outer side of the common bile-duct from the region of the decussation of the inner circular fibres and running inward between the common bile-duct and the duct of Wirsung they finally were seen to terminate by blending with fibres on the inner side of the common bile-duct. These last-named muscle bundles had origin amongst the decussating fibres of the inner circular coat and then curved around the common bile-duct to the inner side of the same and finally blended in part with those fibres which have been described as running between the common bile-duct and the duct of Wirsung.

Fig. 19 is taken at a level still more remote from the duodenal papilla. Passing from the inner side of the intestine toward the outer side we see the mucosa of the intestine, the inner circular muscular coat of the intestine (see *CI*) and the outer longitudinal muscle coat (see *LI*). The lumen of the common bile-duct is prominent (see *B*) and to the right that of the duct of Wirsung. Around the bile-duct longitudinally cut muscle bundles are arranged. They embrace the duct and represent (1) independent muscle bundles embracing the duct

and (2) fibres of the outer longitudinal muscle coat (shown to the extreme right in the drawing) which have run up on the surface of the bile-duct.

Outside the bile-duct and the muscle bundles embracing it are seen muscle fibres cut transversely. On the left, diagonally cut bundles are found running toward this transversely cut muscle. These diagonal bundles represent those fasciculi of the outer longitudinal muscle coat which have curved around at the side of, and also on, the common bile-duct and then have run forward toward the ampulla of Vater (see *LF.*)

In Fig. 20 the typical intestinal wall is shown. The common bile-duct is outside the intestinal wall and a few longitudinal and diagonal muscle bundles are to be seen in its wall. These must be regarded as stray fibres running up on the bile-duct from the intestine and not as fibres of the proper fibro-muscular tunic of the common bile-duct.

V.—THE MUSCULATURE OF THE BILIARY PASSAGES IN MAN.

(*a*) *Gall-bladder.*—What has been said concerning the gall-bladder of the dog may be repeated of the gall-bladder of man. Fig. 21.

(*b*) *Cystic duct.*—Macerations in a mixture of nitric acid, glycerine and water showed the arrangement of smooth muscle to be plexiform. Longitudinal celloidin sections of the cystic duct demonstrated smooth muscle running in three directions, viz. transverse, longitudinal and diagonal. Fig. 22. The transverse bundles are most numerous; the longitudinal and diagonal bundles are about equal in number. In that portion of the cystic duct nearest the neck of the gall-bladder, the amount of muscle is considerable, but this gradually diminishes in amount as the common bile-duct is approached. At the junction of the cystic, hepatic and common bile-duct the quantity of muscle present is very small. These sections also show muscle fibres in those folds of the cystic duct which are known as the valves of Heister. The fact that muscle is present in these folds has been noted before by only one person (A. MacAlister) and he does not undertake to describe the course pursued by the muscle bundles.

In a set of serial longitudinal sections of the entire human cystic duct, I have found the arrangement represented by the following schema. Fig. 23. This schema, based upon study of the serial sections, shows:

(1) That the transverse muscle bundles of the cystic duct are not limited to the wall proper, but at the level of the valves of Heister also run around in the valve in a circular direction. It is just as if the wall of the duct had been invaginated at this level and as a result the circular muscle fibres were carried out into the fold thus formed.

(2) That most of the longitudinal muscle bundles of the cystic duct continue down the duct without entering the valve, but still there are some of these bundles which (having reached the level of the valve) bend around at almost right angle and run out into the fold.

(3) We have no evidence that the diagonal fibres take any part in the musculature of the valves of Heister.

We believe, therefore, that the transverse muscle bundles predominate in the valves of Heister. Those valves nearest the common bile-duct are quite small and either contain very little muscle or none at all.

(*c*) *Hepatic duct.*—The description of the rabbit's hepatic duct applies without any addition to the hepatic duct of man. Fig. 26.

(*d*) *Common bile-duct.*—The muscle fibres could not be detected with certainty in nitric acid, glycerine and water macerations. Longitudinal celloidin sections revealed a small amount of muscle. The direction followed was not only transverse but also longitudinal and diagonal. The number of transverse and longitudinal fibres was about equal; the oblique muscle fibres were least numerous. Much connective tissue was found between the muscle fibres. Fig. 27.

(*e*) *Point of union of cystic, hepatic and common bile-ducts.*—Each duct preserved its typical structure.

(*f*) Preliminary to the description of *the duodenal portion of the human common bile-duct*, it will be well to state that many individual variations in structure occur but that these variations do not alter the general anatomical bearing of this region.

The following drawings have been made from a typical specimen macerated in a mixture of nitric acid, glycerine and water.

Fig. 28 shows the entrance of the common bile-duct *B* and the duct of Wirsung *W* into the intestinal wall. We see a simple separation of the fibres of the outer longitudinal muscular coat of the intestine *LI.* The common bile-duct and the duct of Wirsung pass through this separation. At *F* we find muscle fibres arising from the outer longitudinal muscular coat. These fibres run up on the common bile-duct and becoming gradually less and less marked, finally disappear. This arrangement is bilateral. The fibres marked *IR* represent some bundles of muscle which (shown in Fig. 30, *IR*) form an independent ring of muscle around the common bile-duct between it and the duct of Wirsung.

At *H* are seen muscle fibres which run almost entirely around the duct of Wirsung, but as these fibres approach that side of the pancreatic duct nearest the common bile-duct, they turn abruptly and run up on the duct of Wirsung in a longitudinal direction. They gradually diminish in volume as they ascend the duct. This structure is bilateral. See also Fig. 30, *H.*

Fig. 29 represents the structures seen upon removal of the mucous membrane from the intestinal wall in the region of the duodenal papilla. The inner circular muscular coat of the intestine is represented by *CI.* The first point to demand attention is the penetration of the inner circular muscular coat by the common bile-duct. At the spot of penetration there is a simple separation of the muscle bundles of the inner circular muscle coat. It should be noted that the human specimen differs from the arrangement found in dog. It will be remembered that in the latter animal, the inner circular muscle coat forms a tube-like structure which embraces the common bile-duct for a considerable distance. In man the common bile-duct plunges immediately through the muscle layer which composes the inner circular muscular coat.

At *S* are bundles of muscle running around the common bile-duct (see also Fig. 30, *S*). These are independent rings of muscle which embrace the duct. Now, if we look further

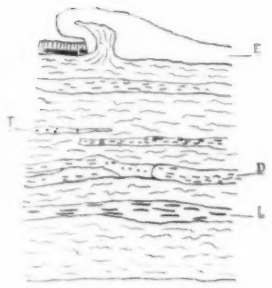

FIG. 1.—Longitudinal section of the gall-bladder of dog. ×30.

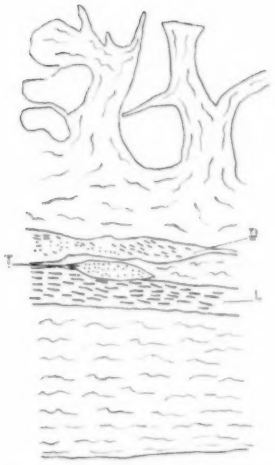

FIG. 2.—Longitudinal section of the cystic duct of dog. ×30.

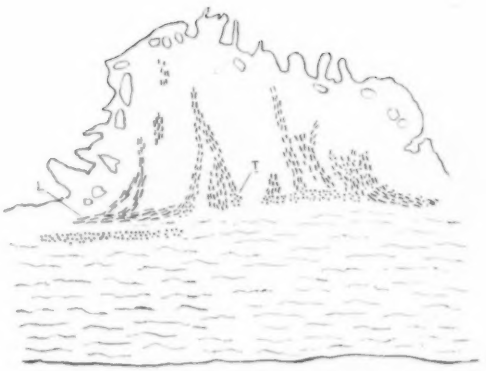

FIG. 3.—Longitudinal section of the cystic duct of dog, showing the musculature of a Heisterian valve. ×30.

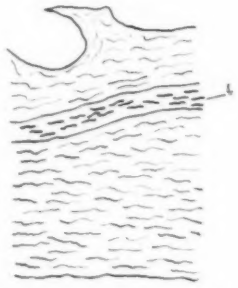

FIG. 4.—Longitudinal section of the hepatic duct of dog. ×30.

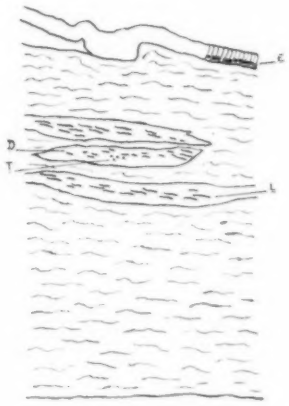

FIG. 5.—Longitudinal section of the common bile-duct of dog. ×30.

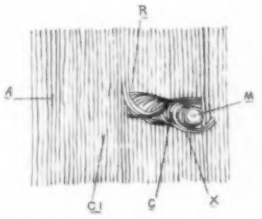

FIG. 6.—Macerated duodenal portion of the common bile-duct of dog. The mucous membrane, muscularis mucosæ and submucosa of the intestine have been removed. ×4.

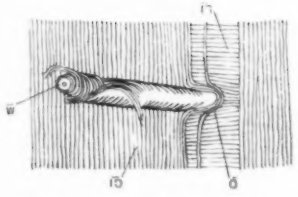

FIG. 7.—Macerated duodenal portion of the common bile-duct of dog. Part of the circular muscular coat of the intestine has been removed. ×4.

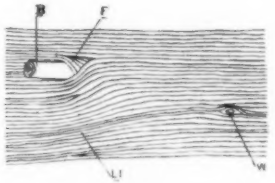

FIG. 8.—Macerated duodenal portion of the common bile-duct of dog. The relation of the common bile-duct to the longitudinal muscular coat of the intestine is shown. ×4.

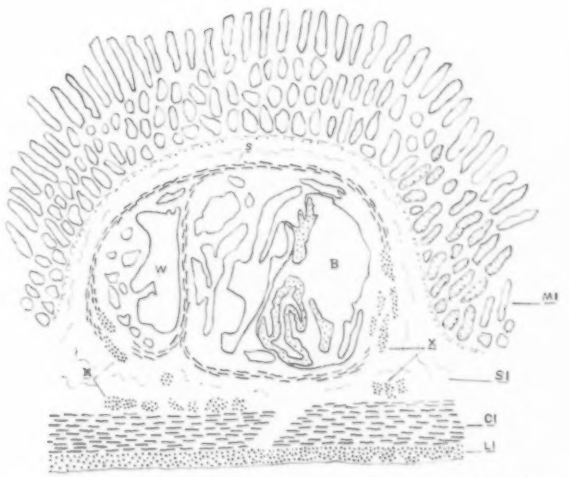

FIG. 9.—Cross-section near the orifice of the duodenal portion of the common bile-duct of dog. ×30.

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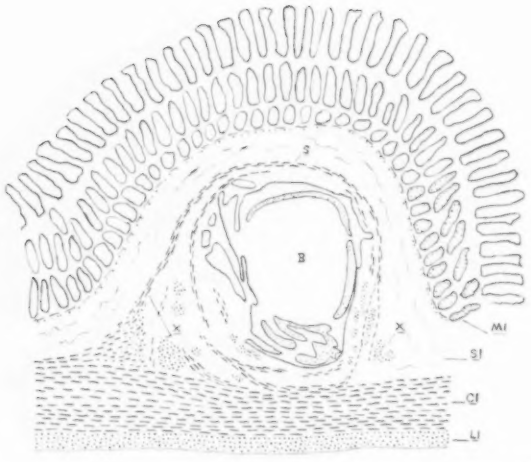

FIG. 10.—Cross-section somewhat removed from the orifice of the duodenal portion of the common bile-duct of dog. ×30.

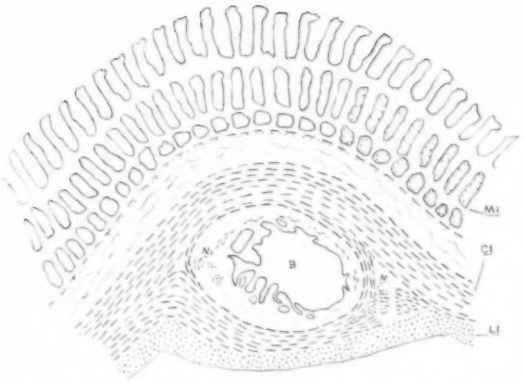

FIG. 11.—Cross-section near the middle of the duodenal portion of the common bile-duct of dog. ×30.

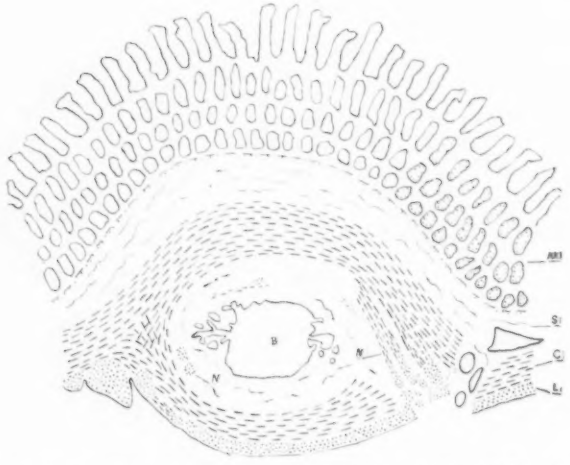

FIG. 12.—Cross-section somewhat removed from the middle of the duodenal portion of the common bile-duct of dog. ×30.

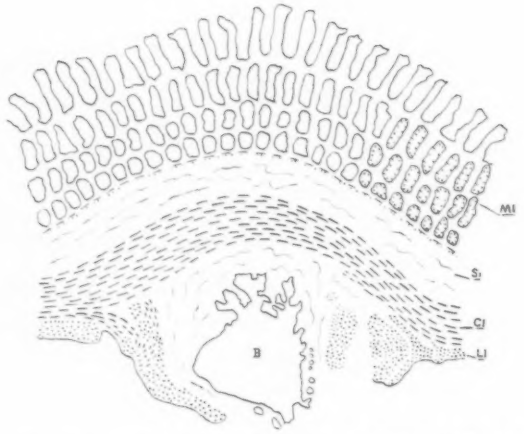

FIG. 13.—Cross-section at the entrance of the common bile-duct into the intestinal wall of dog. ×30.

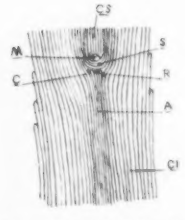

FIG. 14.—Macerated duodenal portion of the common bile-duct of rabbit. The mucous membrane, muscularis mucosæ and submucosa of the intestine have been removed. ×4.

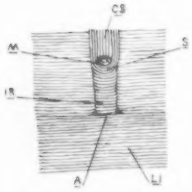

FIG. 15.—Macerated duodenal portion of the common bile-duct of rabbit. The greater part of the circular muscular coat of the intestine has been removed. ×4.

FIG. 16.—Macerated duodenal portion of the common bile-duct of rabbit, showing the distribution of the *CS* and *IR* fibres. ×4.

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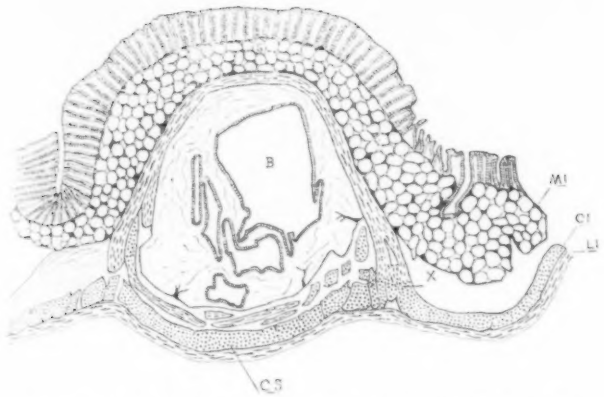


FIG. 17.—Cross-section near the orifice of the duodenal portion of the common bile-duct of rabbit. ×40.

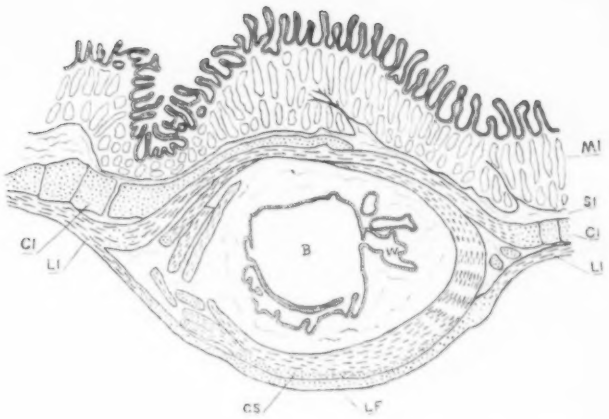


FIG. 18.—Cross-section somewhat removed from the orifice of the duodenal portion of the common bile-duct of rabbit. ×40.

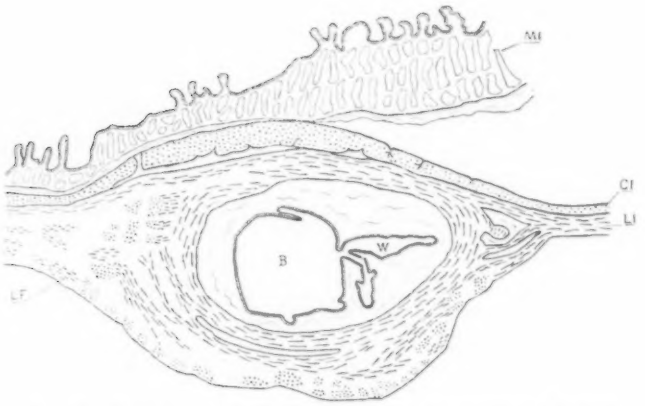


FIG. 19.—Cross-section near the entrance of the common bile-duct into the intestinal wall of rabbit. ×40.

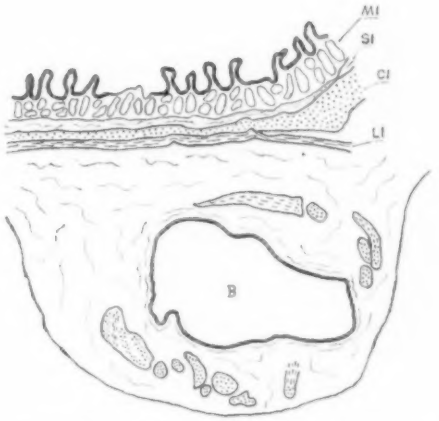
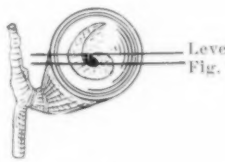


FIG. 20.—Cross-section at the entrance of the common bile-duct into the intestinal wall of rabbit. ×40.



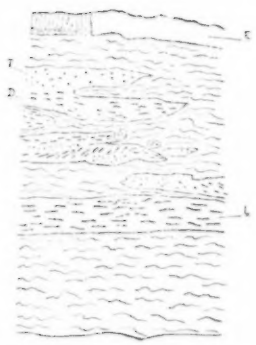


FIG. 21.—Longitudinal section of the gall-bladder of man. ×30.

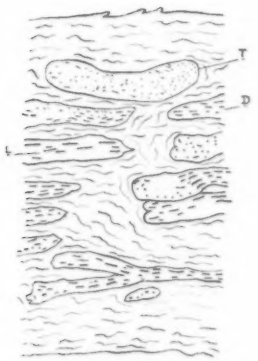


FIG. 22.—Longitudinal section of the cystic duct of man. ×30.

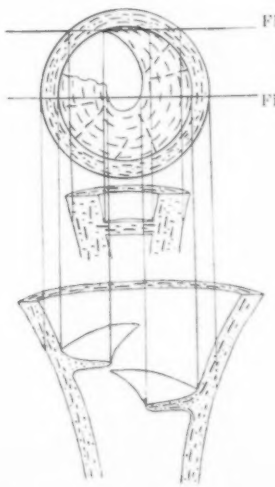


FIG. 23.—The cystic duct of man, showing the Heisterian valve; also, a diagram of the musculature of the Heisterian valve.

Hendrickson, del.

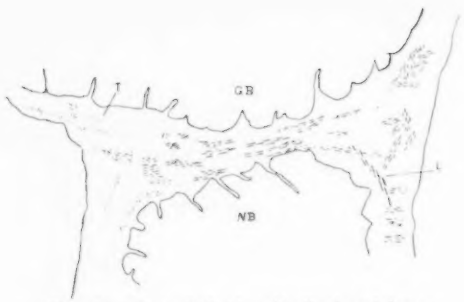


FIG. 24.—One of the longitudinal serial sections of the cystic duct of man. See Fig. 23. × 30.

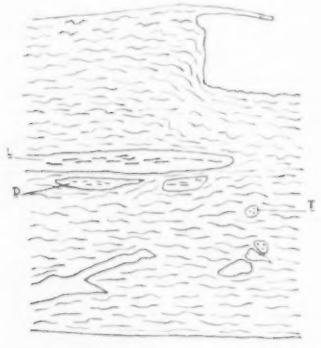


FIG. 26.—Longitudinal section of the hepatic duct of man. × 30.

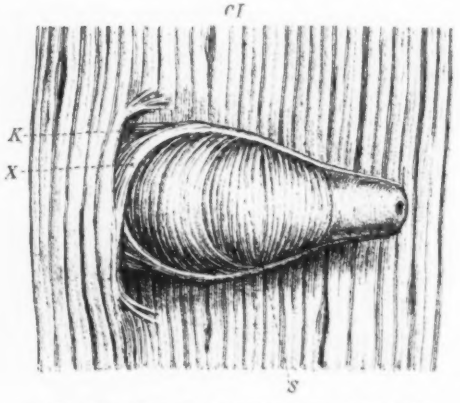


FIG. 29.—Macerated duodenal portion of the common bile-duct of man. The mucous membrane, muscularis mucosa and submucosa of the intestine have been removed. × 5.

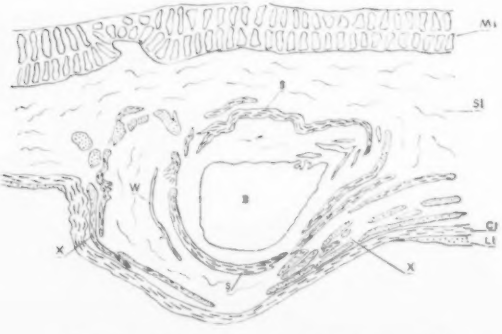


FIG. 31.—Cross-section near the orifice of the duodenal portion of the common bile-duct of man. × 30.

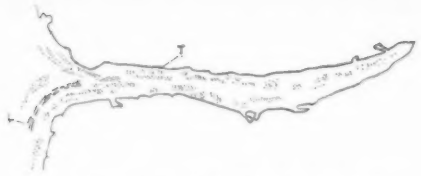


FIG. 25.—One of the longitudinal serial sections of the cystic duct of man, showing the musculature of a valve of Heister. See Fig. 23. × 30.

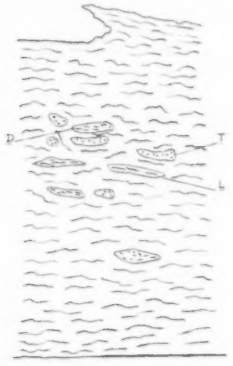


FIG. 27.—Longitudinal section of the common bile-duct of man. × 30.

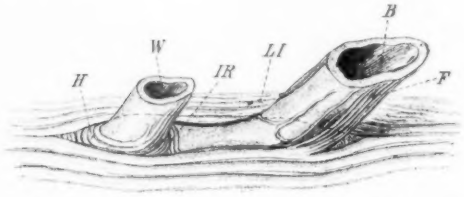


FIG. 28.—Macerated duodenal portion of the common bile-duct of man. The relation of the common bile-duct and the duct of Wirsung to the longitudinal muscular coat of the intestine is shown. × 5.

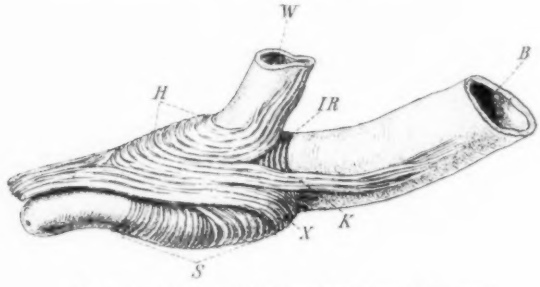


FIG. 30.—Macerated duodenal portion of the common bile-duct of man. All of the intestinal coats have been removed. × 5.

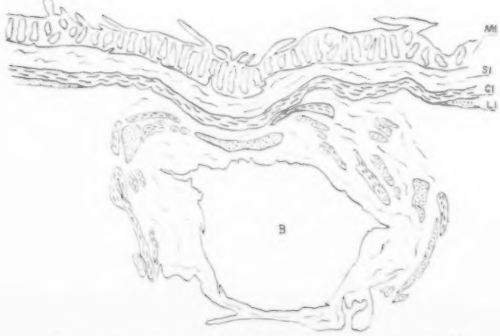


FIG. 32.—Cross-section at the entrance of the common bile-duct into the intestinal wall of man. × 30.

back on the common bile-duct, near the point at which it penetrates the inner circular muscular coat, we observe muscle bundles *X* which do not run entirely around the duct. These muscle bundles are very intimately mixed with the independent muscle rings which completely embrace the duct. The former, however, upon reaching the level of the inner circular muscle coat, turn abruptly forward and under the bile duct, and after running for some distance toward the duodenal papilla finally end in the connective tissue of the submucosa of the intestine (see also Fig. 30, *X*). This arrangement is bilateral. The drawing shows that this arrangement of muscle about the common bile-duct begins at a point before the duct penetrates the inner circular muscular coat. In this particular specimen, a muscle bundle of the inner circular muscular coat curves around and becomes continuous with the fibres marked *X*. It may be well to note that the *X* fibres did not terminate in all cases according to this description. In several cases these fibres, after turning forward and under the common bile-duct, decussated with similar ones from the opposite side and after such decussation became continuous with the fibres of the inner circular muscular coat of the intestine. In one case the *X* fibres after turning forward suddenly plunged through the inner circular muscle coat and became continuous with the fibres of the outer longitudinal muscle coat of the intestine.

Another point observed in some specimens but not in this one is worthy of mention. In some specimens after dissecting away the *S* fibres, a few longitudinally and diagonally disposed fibres were seen. These had origin in those fibres of the outer longitudinal and inner circular muscle coat which lie over the common bile-duct when viewed as in Fig. 29. Finally in Fig. 29 a bundle of muscle fibres *K* can be seen on each side of the common bile-duct running parallel with it. These bundles arise on the surface of the common bile-duct (Fig. 30, *K*) and are covered by the *F* fibres of Fig. 28. In this case they run forward from under the inner circular muscular coat (see Fig. 29, *K*) and bend around beneath the common bile-duct, becoming continuous with each other, thus forming a loop around the duct of Wirsung, Fig. 30, *K*. In other specimens these *K* fibres originate in the same way but terminate by running under the common bile-duct and decussating there with similar fibres from the opposite side.

Fig. 30 shows the muscular arrangement about the end of the common bile-duct and the duct of Wirsung after all fibres of the outer longitudinal and inner circular muscle coats have been removed. The common bile-duct and the duct of Wirsung have been drawn in the same position as they occupied in Fig. 28, but removal of the muscular coats of the intestine permits of a view of the various structures in profile. All the structures here shown have been described more or less fully under Figs. 28 and 29.

After an examination of *serial cross-sections of the duodenal portion of the human common bile-duct*, we have selected two of them for illustration since they represent the principal points. The first figure (Fig. 31) is taken near the level of union of the common bile-duct with the duct of Wirsung. The structures of interest are situated in the submucosa of the intestinal wall. The large opening—to the right—is the lumen of the ductus communis choledochus; the narrow slit—to the left—represents the collapsed lumen of the duct of Wirsung. At the point *X*, muscle bundles cut in cross-section and sometimes diagonally are seen. These bundles represent those fibres of the sphincter muscle which do not run entirely around the common bile-duct. They become detached at the side of the duct from the sphincter proper and turn forward. These bundles then run forward, under the common bile-duct and gradually approach the bundles of the opposite side; they finally end free in the connective tissue of the submucosa near the orifice of the common bile-duct. These bundles correspond to the *X* fibres of the macerated specimen. It is probable that the *K* fibres of the macerated specimen are also included among the bundles described above, but we have not been able to distinguish them in the sections from the others.

The remaining bundles of muscle about the common bile-duct belong to the sphincter muscle proper: they correspond to the *S* fibres of the macerated specimen. A bundle of muscle fibres cut longitudinally is seen running between the lumen of the duct of Wirsung and that of the common bile-duct. I consider this to be a bundle of the sphincter muscle and believe that it corresponds to the "double sphincter" arrangement found in the dog and rabbit, and described above.

The second section (Fig. 32) represents the common bile-duct just before it has penetrated the muscle coats of the intestine. Around the common bile-duct are seen muscle bundles cut transversely. These represent the *K* fibres of the macerated specimen. No muscle fibres arising from the outer longitudinal muscle coat and running up on the common bile-duct can, however, be demonstrated in this specimen.

VI.—CONCLUSIONS.

The principal results of this research may be briefly summed up in tabular form; under the various heads only the most general findings are mentioned.

	Dog.	Rabbit.	Man.
	Distribution of the muscle bundles.	Distribution of the muscle bundles.	Distribution of the muscle bundles.
(a) Gall-bladder	Transverse* Longitudinal Diagonal	Transverse Longitudinal Diagonal	Transverse Longitudinal Diagonal
(b) Cystic duct	Transverse Longitudinal Diagonal	Transverse Longitudinal Diagonal	Transverse Longitudinal Diagonal
Valves of Heister	The transverse fibres of the cystic duct run around in the valves of Heister in a circular direction. The longitudinal fibres bend at a right angle and run out into the valve. Diagonal fibres apparently do not enter the valves of Heister.		
(c) Hepatic duct	Longitudinal	Transverse Longitudinal Diagonal	Transverse Longitudinal Diagonal

*These terms are used with reference to the long axis of the duct.

(d) Common bile-duct	Transverse Longitudinal Diagonal	Transverse Longitudinal	Transverse Longitudinal Diagonal
(e) Place of union of the cystic, hepatic and common bile-ducts	Each duct preserved its typical structure; the wall of each gradually merging into that of the others.	Each duct preserved its typical structure; the wall of each gradually merging into that of the others.	Each duct preserved its typical structure; the wall of each gradually merging into that of the others.
(f) Duodenal portion of the Common bile-duct	A sphincter muscle exists.	A sphincter muscle exists.	A sphincter muscle exists.

VII.—INDEX LETTERING OF THE FIGURES.

B, Common bile-duct.
CI, Circular muscular coat of the intestine.
CS, Fibres of the circular muscular coat of the intestine which have a distribution indicative of a secondary sphincter.
D, Diagonal muscle.
E, Epithelium.
GB, Next to gall-bladder.
IR, Independent rings of muscle embracing the common bile-duct.
K, Fibres which arise on the common bile-duct and run around the duct of Wirsung to become continuous with similar fibres of the opposite side.
L, Longitudinal muscle.
LI, Longitudinal muscular coat of the intestine.
LF, Fibres of the longitudinal muscular coat of the intestine which turn and run forward toward the ampulla of Vater.
M, Mouth of the common bile-duct.
MI, Mucous membrane of the intestine.
N, Muscle bundles which have origin in the median line of the common bile-duct and afterwards run forward parallel with the long axis of the duct.
NB, Next to common bile-duct.
S, Sphincter fibres.
SI, Submucosa of the intestine.
T, Transverse muscle.
W, Duct of Wirsung.
X, Those fibres of the sphincter which become detached laterally and run down the intestine.

DEVELOPMENT OF THE INTERNAL MAMMARY AND DEEP EPIGASTRIC ARTERIES IN MAN.

By Franklin P. Mall.

(*From the Anatomical Laboratory of the Johns Hopkins University.*)

The great importance of the fact that the main arteries of the vertebrates arise directly from the aortic arches has been shown repeatedly in ontogenetic and phylogenetic studies. Furthermore, it gives us a scientific basis for the explanation of the numerous variations which may occur while this simple system of arteries is being transformed into the complex system as found, for instance, in man.

While the modification of the aortic arches is taking place, certain arteries become larger, others disappear, while in others the direction of the circulation is reversed. The laws governing these changes have been discussed extensively by Thoma in his numerous communications. It is the law of use and disuse expressed in this instance by *rapidity*. For a given vessel at a given time in its development there is a certain rapidity of circulation through it at which it ceases to grow. If the rapidity of the circulation is increased the vessel becomes larger; if it is diminished the vessel becomes smaller; if the circulation comes to a standstill the vessel disappears altogether. This law is constantly at work throughout development in the grown animal and in all pathological changes. It does not appear to govern the first growth of the capillaries but it governs the growth of the vessels after the circulation in them is once started.

Any one who has studied the growth of the blood-vessels extensively in living animals as well as in fixed preparations is well aware of the fact that blood-vessels are constantly being formed and destroyed. This process is so extensive that at almost any stage of the development of an animal we may safely say that more blood-vessels have disappeared than are present at that time.

With the above ideas clearly in view, I have studied the extension of the blood-vessels into the body-walls of the embryo to see whether or not some secondary system, regular like the aortic arches, appears to be subsequently converted into the main arteries of the body-walls and the extremities. That the vertebral artery is formed by the union of a number of branches from the descending aorta has been shown by His,* by Froriep† and by Hochstetter.‡ These branches are the segmental arteries from the aorta while it is still in the branchial region. The aorta soon shifts away from the branchial region with the bending of the head and the development of the neck. While this is taking place the segmental arteries unite at their distal ends to form the vertebral artery while the communicating branches are gradually broken off as shown in Fig. 1, *V*, from a human embryo of the fourth week. This process continues down to the seventh cervical segmental artery, where it ceases. At this point the subclavian artery arises, Fig. 1, *S*, as shown by Hochstetter. From now on for a few segments the process is very difficult to follow, but further on throughout the thoracic region of the embryo the process is simple. This is easily accounted for by the perfect segmental arrangement of this portion of the body throughout its development.

There are, however, two other sets of segmental arteries in the thoracic region of the body which appear before this set is formed and gives rise to the arteries of the body-walls. The first set is already well developed in embryos at the end of the second week.§ They arise from the aorta and pass immediately to the umbilical vesicle, there to break up into a plexus which is collected by the omphalo-mesenteric veins. Soon these arteries disappear and the omphalo-mesenteric artery takes their place. These vessels are of course on the mesial side of the cœlom.

* His (W.) Anat. mensch. Embryonen. III. Zur Geschichte der Organe, Leipz., 1885.

† Froriep (A.) Arch. f. Anat. u. Physiol., Anat. Abth., Leipz., 1886, S. 69–150.

‡ Hochstetter (F.) Morphol. Jahrb., Leipz., Bd. xvi, 1890.

§ Mall (F. P.) J. Morphol., Bost., Vol. xii, 1896–7, Fig. 16.

Before this first system has disappeared, and before the permanent intercostal vessels have appeared the second set of segmental arteries arises from the descending aorta, passes on the lateral side of the cœlom into the membrana reuniens, as is indicated to us by a figure given by von Kölliker,* as well as by the description of His.† Von Kölliker pictures a cow's embryo with the whole membrana reuniens filled with a minute plexus of veins which radiate from the myotomes towards the umbilical cord, while His describes this same region in the human embryo as filled with branches of the umbilical vein which empty into the sinus reuniens above, and into the umbilical vein below. According to His's description they arise when the communication between the umbilical veins and the sinus reuniens is severed. Although the picture given by von Kölliker does not correspond with His's description it does not contradict it, nor is it peculiar to the cow's embryo. I have in my collection a well-preserved human embryo (No. LXXVI), in which the membrana reuniens is filled with a plexus of veins much like

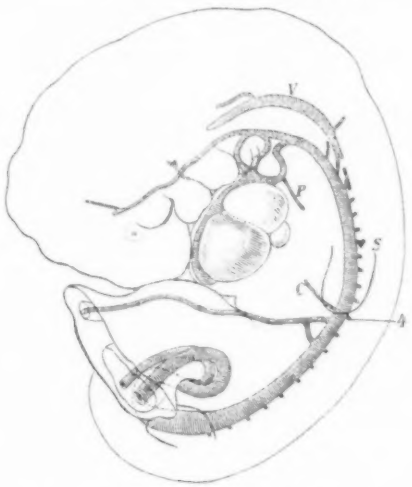


FIG. 1.—Arterial system of a human embryo four weeks old (No. II). Enlarged 10 times. *V*, vertebral artery; *P*, pulmonary artery; *C*, cœliac axis; *S*, subclavian artery; 4, fourth dorsal segmental artery.

that in the cow's embryo. The specimen was taken from the uterus seven hours after the death of the woman, and without opening, the ovum was hardened in absolute alcohol. All the vessels down to the capillaries are filled with blood, thus making it an excellent specimen for the study of the blood-vessels. It represents a stage somewhat more advanced than the one pictured by von Kölliker, as the plexus of veins does not cover the whole membrana reuniens. The ventral wall over the heart near the liver contains no vessels, while the membrana reuniens covering the upper end of the heart is filled with a plexus of vessels which communicate with the capillaries of the mandibular arch. There is an extensive plexus through the arm and lateral body walls which extends through the membrana reuniens covering the liver, and finally encircles the cord and communicates with the umbilical veins.

The specimen just described is about 22 days old and, although I have six other good embryos between 14 and 28 days old, I find no such plexus in the membrana reuniens, although in all but one of them (14 days) the arm shows a rich plexus of capillaries filled with blood. In stages older than four weeks I find no blood-vessels in the membrana reuniens with the exception of that portion encircling the cord, where there is a rich network of veins. Although I have a number of excellent specimens of five or six weeks, the membrana reuniens over the heart and liver contains no blood-vessels until it is invaded by the ventral plate, which is accompanied by the development of the intercostal vessels. In pigs' embryos this extensive membrane is also free from veins, with the exception of the zone encircling the cord, which again has a venous plexus more marked, however, than in the human embryo.

It appears, then, that during the third week of development, while the umbilical veins still empty into the sinus reuniens, an extensive plexus is formed throughout the greater extent of the membrana reuniens, which receives blood from the aorta on its dorsal side, and empties it into the umbilical vein on its ventral side. As the umbilical vein changes its position to enter the liver, this circulation through the membrana reuniens is broken up as the much earlier circulation through the umbilical vesicle was broken up.

The earliest collecting vein for the descending aorta is the omphalo-mesenteric vein; next, it is the umbilical vein, and finally, when the abdominal walls are completed, it is the cardinal. This in turn is partly converted into the vena cava inferior.

The permanent arterial system is already well outlined in embryo II (Fig. 1). The aortic arches and segmental arteries are sufficiently well marked to permit one to number them. The vertebral artery is in process of development, it being formed by a union of a number of segmental arteries, as shown by His, by Froriep, and by Hochstetter. The seventh cervical segmental artery gives rise to the subclavian artery. The lower cervical, all the dorsal and lumbar segmental arteries, are concerned in the development of the thoracic and abdominal walls. Fig. 1 illustrates the extent of the arteries. It shows a simple arrangement from the vertebral to the hypogastric artery. The lower lumbar arteries are not shown. A section of this embryo is given in Fig. 2. It shows the relation of a segmental artery to the myotome. The segmental arteries supply primarily the spinal cord and ganglia by two groups of branches, one near the middle line and one more lateral. A more ventral group of segmental arteries supplies the Wolffian body. The blood from all these groups of arteries is collected by the cardinal veins.

The lateral group gives rise to the intercostal arteries by first supplying the myotome, and, as this grows into the membrana reuniens by a process of budding, the vascular loop follows it. In so doing the loop is first on the dorsal side of the sympathetic and finally on its lateral side, thus making the sympathetic cord cross the intercostal arteries and veins on their ventral side, as is the case in the adult.

No sooner has the vascular loop extended to the lateral side of the sympathetic cord than it begins to anastomose with

*von Kölliker (A.) Grundriss der Entwicklungsgeschichte des Menschen und der höheren Thiere. 8°. Leipzig, 1880. S. 103, Fig. 85.

†His (W.) Anatomie menschlicher Embryonen. III, Zur Geschichte der Organe. Leipzig, 1885, 8°. S. 206, also Fig. 130.

neighboring segmental loops, as single vessels near the subclavian and hypogastric arteries, and as a plexus midway between these two. This gives us at this early period a complete lateral anastomosis from the subclavian artery to the femoral, as Fig. 3 shows. It remains only for this system to shift around towards the median line with the muscle, nerves and ribs to form the condition of things as found in the adult.

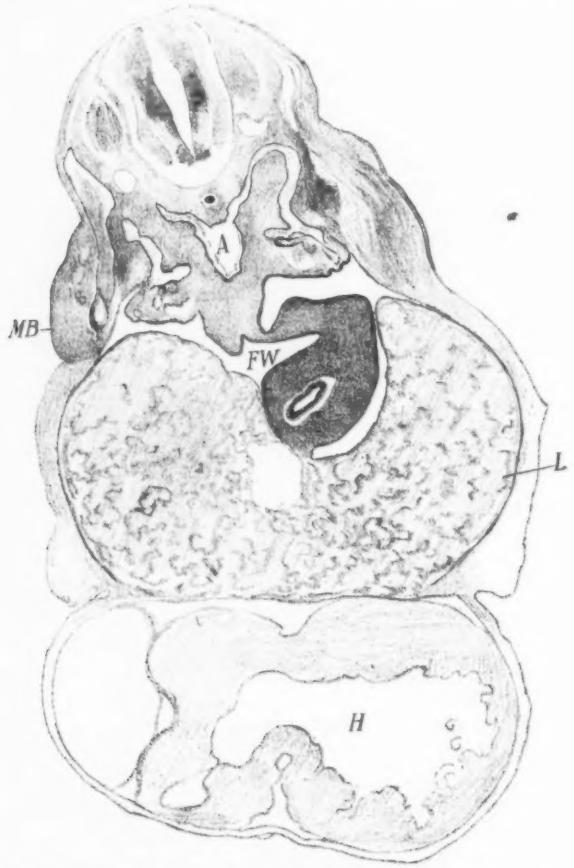


FIG. 2.—Section through a human embryo four weeks old (No. II). Enlarged 55 times. *A*, aorta; *FW*, foramen of Winslow; *MB*, membrana reuniens; *L*, liver; *H*, heart.

Fig. 3 shows that the upper and lower segmental arteries of the series do not correspond at this early time with the same in the adult. Above, the superior intercostal is missing, while below, there is only a small fourth lumbar artery present, and it arises from the middle sacral. Ilio-lumbar and circumflex-iliac arteries are altogether wanting, and I should judge from the relation of the arteries in this embryo, that the arch formed by the ilio-lumbar and circumflex-iliac is of secondary origin and has nothing to do with the segmental arteries. That they form anastomoses with the lower lumbar arteries in the adult can be explained in other ways.

The hypogastric artery is present long before the segmental arteries are formed near its junction with the aorta, and on this account we can no more call the trunk of the common iliac artery segmental than we can apply the same term to the descending aorta. We can only locate its origin in the neighborhood of the fourth lumbar artery.

Hochstetter has settled definitely that the subclavian is a branch from the seventh cervical segmental artery.* Between the seventh cervical and the third dorsal we have three segmental arteries. In Fig. 1 the segmental arteries in this region are all simple with the exception of the seventh, which sends a large branch into the arm. From this stage to the one pictured in Fig. 3 there is a jump, but in it we see the intermediate stage between Fig. 1 and the adult.

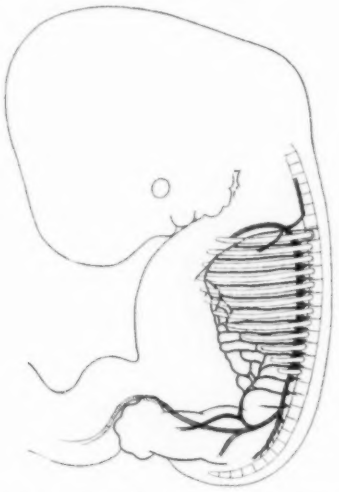


FIG. 3.—Arterial system of a human embryo six weeks old (No XLIII). Enlarged 5 times.

All of the arteries below the vertebral are destined to pass behind the sympathetic, and it is excluded only on account of its direction. In Fig. 3 the eighth cervical segmental passes on the ventral side of the nerve, which shows conclusively that it must either be a new artery or a secondary connection between the eighth segmental and the subclavian. Since the first and second intercostal arteries pass behind the sympathetic in this embryo and in front of it in the adult, we must accept Hochstetter's opinion that the superior intercostal is formed by secondary connections between the upper intercostals and the subclavian. If the old connection remains, it forms the arteria aberrans.

I stated above that the sympathetic lies in front of the subclavian, while in the adult it lies in a great part behind it. Hochstetter explains this change of position by a wandering of the trunk of the artery through the group of embryonic nerve cells. In early embryos the sympathetic system resembles a group of sprouts from the segmental nerves which cross the segmental arteries, and the sympathetic cord is of secondary formation. This cord grows very rapidly during the fifth and sixth weeks, to form a great mass of cells extending from the vagus gang-

* Hochstetter numbers the segmental arteries to correspond with the vertebræ above them. Throughout I number the arteries with their accompanying nerves. He states that the subclavian arises from the sixth segmental, this being the same artery that I call the seventh cervical segmental.

lion to the adrenals, connecting all of the branches with the segmental nerves to make of them rami communicantes. This all goes on hand in hand with the descent of the heart into the thorax. At the same time the arm is rotating towards the ventral median line, and drags with it the subclavian artery. In so doing the subclavian is dragged into the sympathetic cord in its earliest stage, thus allowing the greater portion of the cord to be developed on its dorsal side. The portion of the sympathetic which from the first lies on the ventral side of the subclavian becomes the ansa subclavia.

The descent of the heart into the thorax on the inside with the descent of the arm over the clavicle on the outside of the body causes great tension on the upper intercostal arteries, and favors the new formation of blood-vessels in a more direct line. This is the reason why the main branch of the superior intercostal is a secondary and direct artery from the subclavian.

The simple diagram, Fig. 4, shows the origin of the main arteries of the trunk from the aortic arches and segmental arteries. This compared with Figs. 1 and 3 will explain itself. In the diagram the vessels which remain are black; those which disappear, outlined; and those new formed, striated.

Résumé :—While the aortic arches are forming, the arteries arising from the descending aorta pass on the mesial side of the cœlom to the umbilical vesicle, and the blood passing through them is collected by the omphalo-mesenteric veins. Soon the segmental arteries arise, unite and shift backwards in the head region to form the vertebral artery. In the trunk they also unite within the lateral body-wall to form the internal mammary and deep epigastric arteries. This anastomosing arch, lying immediately below the tips of the ribs and the rectus abdominis muscle, wanders with them to the ventral middle line, the communicating branches forming the intercostal arteries. The whole course of the anastomoses between the tips of the segmental arteries takes on in its wandering the shape of the letter Z (Fig. 4), the upper angle marking the origin of the subclavian. With the rotation and descent of the arm the subclavian is dragged partly through the sympathetic cord; the origin of the superior intercostal is shifted, by the formation of a new anastomosis, from the dorsal to the ventral side of the sympathetic cord.

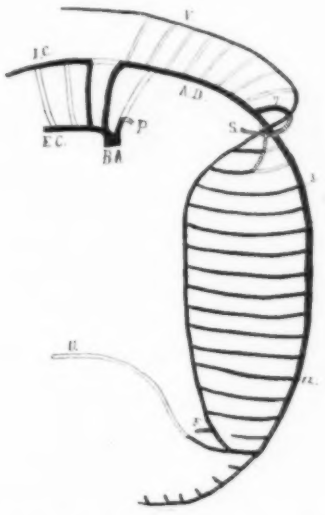


FIG. 4.—Diagram to show the development of the arteries of the trunk from the aortic arches and segmental arteries. The arteries which remain are black; those which degenerate are outlined; those newly formed are striated. *I. C.*, internal carotid; *E. C.*, external carotid; *B. A.*, bulbus aortae; *P.*, pulmonary artery; *A. D.*, descending aorta; *V.*, vertebral; *S.*, subclavian; *F.*, femoral; *U*, umbilical; 7, seventh cervical; 3 and 12, third and twelfth dorsal.

The first vein collecting the blood from the abdominal aorta is the omphalo-mesenteric; next the umbilical, and finally, the cardinal assumes this function.

TWO INSTANCES IN WHICH THE MUSCULUS STERNALIS EXISTED.—ONE ASSOCIATED WITH OTHER ANOMALIES.

HENRY A. CHRISTIAN.

(*From the Anatomical Laboratory of the Johns Hopkins University.*)

During the past winter, two specimens of the musculus sternalis were found in the dissecting rooms of the Anatomical Laboratory of the Johns Hopkins University, and at the suggestion of Dr. Mall I make the following report of them. Both specimens occurred double in well developed white, male cadavers.

That the simple report of such anomalies can have little value in itself, is fully recognized; but by recording such cases material will be accumulated, from which in the future generalizations can be drawn and perhaps some light thrown on the origin of such muscles as well as of the general body musculature. Realizing this I report the following two cases, which have perhaps an additional interest in that each represents a distinct form of this anomaly and one is further associated with a series of variations confined to the regions from which the sternalis arises.

Specimen I.—The M. sternalis is well developed on both right and left sides. Unfortunately, however, an incomplete autopsy has partially mutilated the muscle of the right side, thus somewhat obscuring its true relations. However, as seen, the two muscles appear symmetrical and about equally developed. As shown in (Fig. 1) these supernumerary muscles have their origin in part by tendinous fibres arising from the lower two-thirds of the manubrium sterni medial to the origin of the M. pectoralis major, in part by fibres continuous with the tendinous attachment of the sternal portion of the M. sterno-cleido-mastoideus. The larger number of the fibres arising from the tendon of the M. sterno-cleido-mastoideus cross to

the tendon of the M. sternalis of the opposite side, those from the right side passing ventral to those from the left, while a part are continuous with the tendon of the same side. The tendon thus formed continues to the second intercostal space, where the muscle fasciculi begin and soon spread out into a flat thin muscle about three centimeters in breadth. This muscle, slightly increasing in breadth, continues down to the fifth intercostal space, where it ends by an insertion into the fascia covering the M. rectus abdominis, a little below its point of origin. In its course the M. sternalis lies over the sternal origin of the M. pectoralis major and receives its nerve supply from a branch (anterior cutaneous) of the III intercostal nerve, which perforates the M. pectoralis major and becomes lost in the substance of the M. sternalis.

Specimen II.—On the right side the muscle arises from the tendon of the M. sterno-cleido-mastoideus and the thick fascia over the sternum (Fig. 2), extending as low down as the second rib. In addition a fasciculus arises from the second rib. This smaller fasciculus joins the main muscle on its lateral side in the region of the fourth rib. The main tendon becomes muscular at the third rib, from which place it continues down to be inserted into the fifth rib about three cm. from the sternum. In the third intercostal space this muscle receives a very minute filament from the anterior perforating cutaneous branch of the intercostal nerve, and also a larger twig from the outer cord of the brachial plexus. This latter nerve may be traced for 6 cm. running on the M. pectoralis major. It then pierces the M. pectoralis major over the third rib to continue upward between the M. pectoralis major and M. pectoralis minor to the upper border of the latter, where after passing beneath the acromial branch of the acromio-thoracic artery, it ends by joining the outer cord of the brachial plexus.

On the left side a much smaller fasciculus arises from the fascia over the first interspace. This soon becomes muscular, spreading out into a very thin muscle, which is inserted into the fifth rib. The nerve supplying this muscle can be traced to the anterior thoracic nerve, having a very similar course to that of the nerve supplying the muscle of the right side.

The musculus sternalis was noted by Cabrolius in 1604, and first accurately described by Du Puy in 1726. From the time of Du Puy down to the present, literature furnishes descriptions of about 175 well authenticated cases—a number apparently sufficient to enable us to safely generalize.* Unfortunately, however, none of these early descriptions note the innervation. Although Hallet (1848) reported a case receiving its nerve supply from the III, IV and V intercostal nerves, and Malbranc (1876) by electrical stimulation on living subjects found a M. sternalis supplied from the intercostals, and another from the anterior thoracic, Cunningham was the first to fully recognize the value of the nerve supply in studying the origin of this muscle. This view is fully supported by recent studies in comparative myology as well as by the study of the development of the skeletal muscles. This information being recent the earlier writers make no mention of the nerve supply, and their reports are, from our present point of view, of scarcely more than historical interest, showing only the various forms that may occur. Since it appears that "all of the muscles arising from a myotome are always innervated by branches of the nerve which originally belonged to it" (Mall), it is evident that the origin of a muscle variation can only be studied to advantage when its nerve supply is given. Reviewing the literature from this standpoint I find that in but eighteen instances the nerve supply of the M. sternalis is given. To these I add two, making twenty in all, as shown in the accompanying table.

Can we infer anything as to the origin of this anomaly from these twenty specimens tabulated below? That there have been many views as to the origin of this muscle, is shown by the various names (M. sternalis, M. presternalis, M. episternalis, M. sternalis brutorum, M. rectus thoracicus, M. rectus thoracis, M. rectus sternalis, M. accessorius ad rectum) which from time to time have been applied to it. The main hypotheses which have been advanced regarding the origin of this muscle are as follows:

(a) It is an upward extension of the M. rectus abdominis.

(b) It is a downward extension of the M. sterno-cleido-mastoideus.

(c) It is a remnant of a panniculus carnosus and to be associated with the platysma myoides in man.

(d) It is an aberrant portion of the M. pectoralis major.

In 1876 Bardeleben concluded from the standpoint of morphology that not one but several different muscles had been described under the name of M. sternalis, and that of 120 cases, which he tabulated, 7 per cent. were varieties of the M. rectus abdominis, 21 per cent. of M. pectoralis major, 55 per cent. of M. sterno-cleido-mastoideus and 6 per cent. skin muscles.

Of the earlier cases reported, it is possible that some may have been genuine cuticular muscles, but that a muscle, which we would now class as M. sternalis, could have such an origin is not possible since it lies in a plane deeper than the platysma myoides, the representative of this class in man. Further to be an aberrant portion of this cuticular muscle, it should be innervated from above the brachial plexus, a condition which we have not as yet found to exist. That it is not a strictly downward extension of the M. sterno-cleido-mastoideus, though the majority of the muscles are connected by their tendons of origin with the M. sterno-cleido-mastoideus, we conclude from the fact that it does not have a similar nerve supply.

*The following will show the relative frequency of occurrence of this anomaly:

Wood	7	examples in	175	cadavers.
Turner	21	" "	650	"
Gruber	5	" "	95	"
Macalister	21	" "	350	"
Le Double	33	" "	722	"
Christian	2	" "	70	"
Total.	89	" "	2062	"

About 4¼ per cent.

TABLE GIVING THE ORIGIN, INSERTION AND INNERVATION OF THE MUSCULUS STERNALIS.

Observer.	Side.	Origin.	Insertion.	Nerve Supply.	Remarks.
1. Fick, A. A. VI-S. 601.	R.	Tendons of sterno-mastoid on both sides and upper digitations of pectoralis major on both sides.	Rectus sheath at VI and VII ribs, digitations of ext. oblique arising from V rib and from fascia over sternum at level V rib.	III and IV intercos.	Intra vitam contracted with sterno-mastoid in raising head.
2. Fick.	R.	Digitations of pectoralis major by means of two horizontal tendons to right and left at upper edge III rib.	Rectus sheath at VI and VII ribs and fascia of lowest digitations of pectoralis major.	IV intercos.	
3. Fick.	R.	Tendon left sterno-mastoid, few fibres from tendon right sterno-mastoid, manubrium sterni and upper digitations of pectoralis major of both sides.	Rectus sheath at V and VI ribs and fascia of pectoralis major and fasciculi to III, IV and V ribs.	II, III and IV intercos.	Motion with sterno-mastoid observed.
	L.	Manubrium sterni and upper digitations of pectoralis major of both sides.	Rectus sheath at VI rib, and a deeper layer to V rib and intercostal membrane between V and VI ribs.	III and IV intercos.	
4. Bardeleben, A. A. III-S. 324.	R.	Tendon sterno-mastoid.	Rectus sheath at VI rib and two thin fasciculi to left pectoralis major.	II and III intercos.	
5. Bardeleben.	R.	Right tendon sterno-mastoid.	Rectus sheath at VI rib.	II and III intercos.	
	L.	Both tendons of sterno-mastoid.	Rectus sheath at VI rib.	II and III intercos.	
6. Bardeleben.	R.	Right tendon sterno-mastoid.	Rectus sheath at VI rib.	II intercos.	
7. Bardeleben.	R.	Manubrium sterni.	Rectus sheath.	II intercos.	
	L.	Manubrium sterni.	Rectus sheath.	II intercos.	
8. Bardeleben.	R.	Fascia of pectoralis major at II rib and left sterno-mastoid.	Rectus sheath at V rib.	III intercos.	
9. Bardeleben.	R.	Right sterno-mastoid and some fibres from left pect. major.	Rectus sheath.	III intercos.	
10. Bardeleben.	(?)	Manubrium sterni.	Rectus sheath.	III and IV intercos.	
11. Bardeleben.	(?)	Manubrium sterni.	Rectus sheath.	III (?) intercos.	
12. Shepherd, Jour. Anat. and Phys. XIX-p. 311.	L.	Both sterno-mastoids and right pectoralis major.	IV costal cartilage, border of sternum opposite V and VI ribs and aponeurosis of ext. oblique.	Int ant. thoracic.	Anenceph.
13. Shepherd.	L.	Sterno-mastoid.	III costal cartilage and border of sternum.	Ant. thor. (?)	
	R.	Sterno-mastoid and sternum opposite II and III rib.	Fasciculus into lower segment pectoralis fascia continuing with fibres of pector., lower end of sternum and ensiform cart.	Ant. thor. (?)	
14. Shepherd.	L.	Sternum opp. II rib.	Aponeurosis of ext. oblique.	Int. ant. thor. and III intercos.	
15. Shepherd.	L.	Sterno-mastoid and right pector.	III costal cartilage.	Int. ant. thor.	
16. Shepherd.	L.	Pect. major over manubrium sterni.	IV costal cartilage and fasciculus into fascia over pectoralis major.	Int. ant. thor.	
	R.	Pect. major over manubrium sterni.	A slip to fasc. over pect. maj. and a second to same lower down.	Int. ant. thor.	
17. Shepherd.	R.	Manubrium sterni.	Pectoralis major and sternum opposite IV costal cartilage.	Int. ant. thor.	
	L.	Manubrium sterni.	One fasc. to III cost. cart., a second to lower sternum and third to fasc. over pect. major.	Int. ant. thor.	
18. Wallace, Jour. Anat. and Phy. XXI-p. 153.	R.	Right tendon sterno-mastoid and few fibres from left pectoralis major.	III, IV, V and VI costal cartilages and border of sternum.	Ext. ant. thor.	
19. Christian, Specimen I.	R.	Manubrium sterni and both tendons of sterno-mastoid.	Rectus sheath at V rib.	III intercos.	
	L.	Manubrium sterni and both tendons of sterno-mastoid.	Rectus sheath at V rib.	III intercos.	
20. Christian, Specimen II.	R.	Tendon of sterno-mastoid, fascia over manubrium sterni and a small fasciculus from II rib.	V costal cartilage.	Branch from Brachial plexus and a small twig from intercos.	
	L.	Fascia over I interspace.	V costal cartilage.	Ant. thoracic.	

Between the two remaining hypotheses there has been much discussion. Bardeleben advanced the theory that it belonged to the same plane of muscles as the M. rectus abdominis and M. sterno-cleido-mastoideus, and Testut the theory that it represents a connecting link between the M. obliquus abdominis externus and M. sterno-cleido-mastoideus, a condition normally found in the snake. However, Le Double claims that this latter condition does not hold and that the muscle found in the snake is represented in man by a deeper layer. It is probable that there is no exact analogue of this muscle in the lower animals. In some animals, as the Armadillo, beaver and Echidna the M. sterno-cleido-mastoideus extends down on the sternum (Turner) but not so far as the VI rib, and there is no connection with the M. rectus abdominis, which lies in a deeper plane. In all cyano-morphous primates (Keith) a M. supracostalis anterior occurs which is a digitation of the M. rectus abdominis arising from the I rib, but this lies beneath the M. pectoralis major. However there can be no doubt that Bardeleben was justified in his conclusion that a close relationship exists between the M. sternalis and the M. rectus abdominis since he and others have reported undoubted cases where the M. sternalis received its nerve supply from the intercostal nerves in a manner similar to the M. rectus abdominis.

This view of Bardeleben was generally accepted until P. S. Abraham reported some cases in anencephalic monsters, receiving nerves from the brachial plexus through the anterior thoracic branches. Soon after this Cunningham reported similar cases from adult cadavers. Such a nerve supply suggested a close relationship with the M. pectoralis major and from the fact of the long course of the nerve through and over the M. pectoralis major and from the recurrent course of many of the lower anterior cutaneous branches of the intercostal nerves perforating the fascia beneath the M. sternalis to run around the inner border of this muscle, it was concluded that it is an aberrant portion of the M. pectoralis major which had rotated inward and downward to this present position. This conclusion seems to be fully in accord with the facts and to be justified by the nerve supply which we regard as the link between present position and the myotome from which it arose. That this muscle is really often innervated from the brachial plexus is further shown by the contraction of the M. sternalis when the brachial plexus is electrically stimulated.

Here then we have two views as to the origin of this muscle, conflicting but both apparently well justified. Can these views be in any way harmonized? From the twenty cases tabulated above it is readily seen that these muscles divide naturally into two classes, one with a fixed insertion into the middle ribs or margin of the sternum and supplied by nerves from the brachial plexus, the other with a less fixed insertion into the sheath of the rectus and a nerve supply from the perforating branches of the intercostal nerves, the origin of the two classes being very similar. From this we conclude that in the musculus sternalis we have a muscle functionally always the same —probably antagonistic to the triangularis sterni—but that we have included under one term two distinct muscles, one closely related to the M. rectus abdominis, and the other an aberrant portion of the M. pectoralis major, the former supplied from the intercostal nerves and arising in the embryo from thoracic myotomes, the latter supplied from the brachial plexus and arising from cervical myotomes. Therefore, from the standpoint of innervation and development we agree with the results obtained by Bardeleben that the name M. sternalis has been used as a general term and that it should be reserved for those presternal muscles associated with the M. pectoralis major, while the name M. rectus thoracis should be applied to those related to the M. rectus abdominis.

The cadaver from which specimen No. 1 was taken showed a number of additional muscle anomalies in the region of the course of travel which must have been followed by M. sternalis in its development. When one sees a marked anomaly he should look for and will frequently find associated variations. These may indicate the forces at work to produce variation, and for this reason I enumerate those which accompanied Specimen I.

Musculus cleido-hyoideus.—A M. cleido-hyoideus (Fig. 3) is found on the left side, occurring with no variations in the M. sterno-hyoideus, M. sterno-thyroideus or M. omo-hyoideus. It occurs as a thin narrow ribbon of muscle fibres more delicate than the M. omo-hyoideus. It arises from the body of the hyoid bone just above and overlapping the external third of the M. sterno-hyoideus and internal half of the M. omo-hyoideus. From this origin it passes downward and slightly outward to be inserted into the clavicle just posterior to the clavicular insertion of the M. sterno-cleido-mastoideus. Just before reaching the clavicle the muscle spreads out fan-like to be inserted by an aponeurosis about twice the breadth of the muscle and extending along the clavicle from a little internal to the middle point of the insertion of the M. sterno-cleido-mastoideus to a point about one cm. external to its insertion.

Quite frequently the M. omo-hyoideus gives off a slip to be inserted into the clavicle and consequently this muscle may be regarded as an aberrant portion of the M. omo-hyoideus here entirely split off except at its very origin. Its nerve supply is apparently the same as that of the M. omo-hyoideus, a fact supporting this view of its histogenesis.

M. sterno-thyroideus.—On the left side the M. sterno-thyroideus is normal as to its size and attachment. The muscle of the right side is fully twice as broad as that of the left and somewhat thicker. Its origin from the sternum is normal. Its insertion is by three heads, each more or less distinct. Of these the inner is inserted as usual on the inferior surface of the oblique ridge of the thyroid cartilage and represents in size and insertion almost the normal muscle. The middle head continues up closely associated with the outer border of the M. thyro-hyoideus, which latter is somewhat narrower than the one of the opposite side. Most of the fibres of this head are inserted into the anterior inferior and middle border of the hyoid bone, while a few are inserted into the middle part of the superior border of the thyroid cartilage. The outer head consists of a distinct ribbon of fibres running up to be inserted into the deep cervical fascia and sheath of the carotid artery intimately blending with these structures. The main part of the muscle is supplied by a branch from the hypoglossal loop, while the middle and outer heads receive fibrils from a branch of the hypoglossal nerve given off above that to the M. thyro-hyoideus.

M. hyo-cornicula laryngis (*M. hyo-cartilago santoriniana*).—

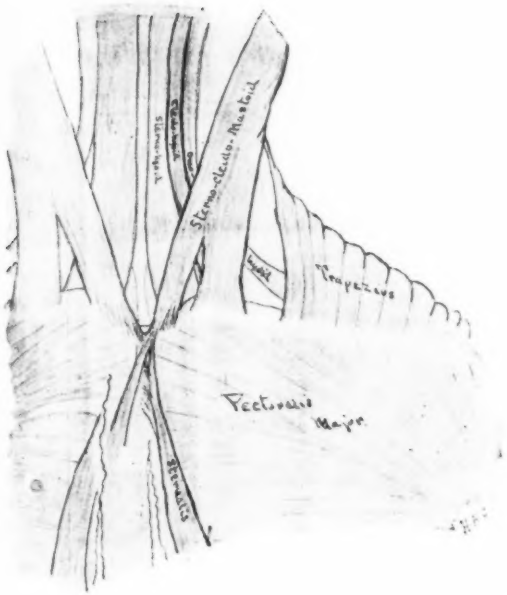


FIG. 1.—Sketch showing the attachment of the M. sternalis in Specimen No. I.

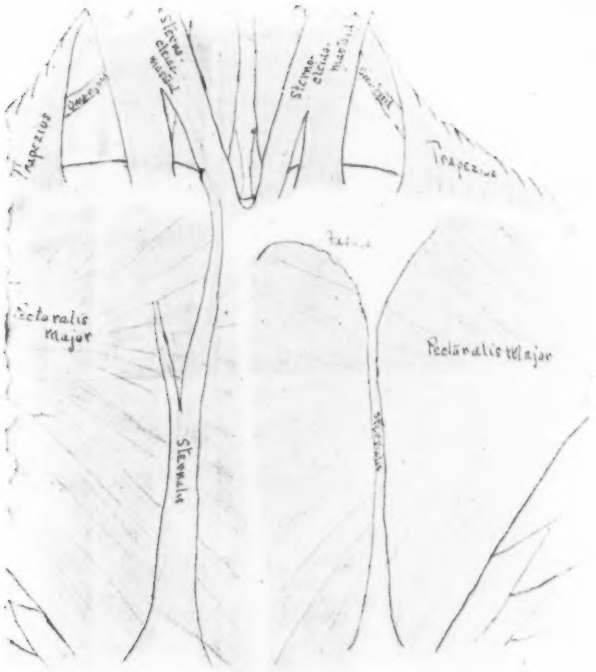


FIG. 2.—The attachment of the M. sternalis in Specimen No. II.

FIG. 3.—The neck of Specimen I, to show the attachment of the M. cleido-hyoideus to the clavicle.

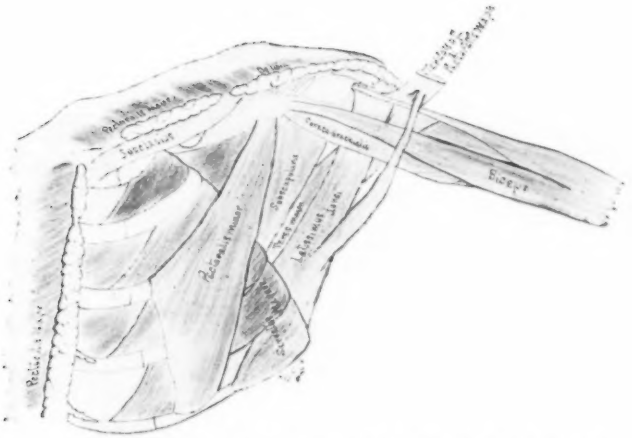


FIG. 4.—The axilla of Specimen No. I, to show the slip from the M. latissimus dorsi to the pectoralis major.

Christian, del.

Arising on the right side from the tendinous portion of the M. digastricus, where it is held down to the hyoid bone by a strong loop of fascia, is found a small muscle about one cm. wide, nearly cylindrical in shape and running downward and outward around the larynx for about 6 cm. to be inserted into the fascia about the cornicula laryngis (cartilage of Santorini). Its nerve supply consists of a fine fibril arising from the hypoglossal nerve.

M. trapezius.—The M. trapezius of the right side gives off a fasciculus about 5 cm. wide and 1.5 cm. thick which is inserted into the clavicle at the inner part of its middle third just external to the origin of the clavicular portion of the M. sterno-cleido-mastoideus. This fasciculus extends upward to join the anterior border of the main portion of the M. trapezius about 10 cm. from its insertion into the occipital bone. No special distinct nerve supply could be found for this fasciculus.

M. latissimus dorsi.—On each side of the subject the M. latissimus dorsi (Fig. 4) possesses an accessory tendon of insertion. The larger normal tendon passes as usual beneath the axillary artery and brachial nerves while the accessory tendon passes over, thus forming an arch for the nerves and vessels. The regular head is inserted into the bicipital groove of the humerus while the accessory one is inserted along with the tendon of insertion of the sternal portion of the M. pectoralis major into the anterior bicipital ridge. The tendinous fibres of this latter are intimately associated with the pectoral tendon for about 2 cm. and then separating pass down as a rounded tendon to join the muscle fasciculi which come off from the main muscle about 6 cm. from its humeral insertion. The accessory head thus formed is about one-fifth the size of the other tendon, which is normal and 7.5 cm. in length.

The two heads form a triangle with the long and short heads of the M. biceps and M. coraco-brachialis as a base. Through this pass the axillary artery and vein, the median, musculo-spiral, ulnar, internal cutaneous and lesser internal cutaneous nerves. So far there is almost perfect symmetry in these structures on the two sides of the cadaver, but the nerve supply to each head is apparently different, though the ultimate origin of the individual nerve fibres from the cord may possibly be quite the same.

The accessory head of the M. latissimus dorsi of the left side is supplied and apparently solely supplied by a rather small nerve entering the muscle substance. This can be traced up to the lower border of the M. pectoralis minor, there to join a nerve which is unmistakably the internal anterior thoracic, since it supplies the M. pectoralis minor sending some of its fibres through this muscle to supply the M. pectoralis major. On this side of the body the internal anterior thoracic nerve arises by two divisions and probably receives fibres from the VII and VIII cervical nerves.

On the right side, at first sight, the accessory head would seem to receive its nervous supply from the II and III intercostal nerves, since two stout branches from these sources enter the muscle substance. However, on closer examination, these appear to pass through the muscle substance without giving off any fibres to the muscle and to end further on as cutaneous nerves. As no other definite nerve fibre could be traced to this head, it must be supplied by a fibre from the middle or long subscapular nerve, running up in the muscle substance from the main muscle body. If this be the case these fibres would ultimately have about the same source in the cord as those supplying the accessory head on the left side as may be seen by comparing the diagrams of the two plexuses.* On the right side the long subscapular nerve arises from the posterior cord of the plexus just after this cord receives a branch from the inner cord. Thus this long subscapular nerve probably consists of fibres from the VII and VIII cervical nerves, the same nerves as those supplying fibres to the accessory head of the M. latissimus dorsi of the left side through the branch from the internal anterior thoracic nerve.

On neither side does the M. latissimus dorsi receive a slip from the tip of the angle of the scapula.

M. extensor carpi radialis accessorius.—This muscle occurs only in the right arm. Its origin is from the radial side of the M. extensor carpi radialis longior by a slip separating about 4 cm. from the origin of this muscle. About 5 cm. above the annular ligament this slip becomes muscular. Just above the ligament it passes under the tendon of the M. extensor carpi radialis longior to be inserted with the M. extensor carpi radialis brevior into the base of the metacarpal bone of the middle finger. It is innervated by a branch of the musculo-cutaneous nerve.

M. extensor digiti tertii.—Occurs only in left hand. Its origin is from the posterior shaft of the ulna below the origin of M. extensor indicis. Its tendon passes down with that of the M. extensor indicis through the same compartment in the annular ligament, and is inserted finally into the tendon of the M. extensor communis digitorum belonging to the middle finger and on its ulnar side. Its nerve supply is from the posterior interosseous branch of the musculo-spiral nerve.

Scapula.—On either side of the body, the tip of the acromial process is separate from the scapula, being connected to the spine of the scapula by a firm ligamentous band of connective tissue surrounding the proximal ends of bone lying in juxtaposition. The ends of the bones are covered with cartilage, and all are so firmly bound together that very little motion is possible.

All of these eight variations, in addition to the M. sternalis, are along the course the diaphragm takes in its excursion, during development, from the neck to its permanent location. It is to be noted that all this takes place before the embryo is four weeks old, and that at this time the muscles are just beginning to be formed from the myotomes.

Aug. 22, 1898.

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ON THE PATHOLOGICAL CHANGES IN THE SPINAL CORD IN A CASE OF POTT'S DISEASE.

By Sylvan Rosenheim.

(*From the Anatomical Laboratory of the Johns Hopkins University.*)

That scientific advances go hand in hand with improvements in the methods of research has nowhere been better demonstrated, perhaps, than in the study of the central nervous system. Early in this century much was accomplished by mere dissections and sectioning of the various parts of the nervous system, but the greatest strides have occurred since Weigert, in 1884, published his method of staining the myelin sheaths of the nerve fibres. Of the various methods employed to isolate the tracts in the spinal cord, that depending on the degeneration following severance of the connection between a nerve fibre and its trophic centre, namely, the cell-body from which it arises, has been one of the most important.

It is this method of study which has been utilized in the present case, in which the spinal cord was pressed upon by a tuberculous exudate. The methods of Weigert and Marchi have both been employed. It has been possible, by a combination of the two methods, to determine the extent of the degeneration following the compression, and to distinguish the more recent degenerations from those which occurred at an earlier date.

The case is also interesting in view of the light it throws upon some of the more recent problems in connection with the study of the spinal cord, especially

(1) The finer histological changes about the site of primary lesion, and

(2) The paths which descend in the dorsal funiculi.

I wish to thank Dr. Barker for his aid in this study.

CLINICAL HISTORY.

The patient, H. H., a female, colored, æt. 15 years, entered Professor Osler's wards of the Johns Hopkins Hospital October 10, 1895, complaining of loss of power in the legs.

Family History.—Father and mother living and well. One of her brothers, who died at the age of 7 years, had contraction of the lower extremities, similar to that from which the patient suffers, one month before his death. Grandmother, on the paternal side, died of a "heavy cough"; she was very emaciated before death. An aunt on the mother's side is a consumptive.

Personal History.—Patient has had no scrofulous breaking down. Menstruation not yet established. At the age of 6 years the patient was gradually attacked with loss of sensation in the feet, which was shortly afterwards followed by loss of power, and she was confined to her bed for three weeks, when she gradually regained power. She was able to run, walk and skip, and was in good health up to last February. Every winter she suffers from a cough, which lasts until the spring to return again the following winter. Thick white expectoration is associated with the cough.

Present Condition.—In February, 1895, the patient was attacked by influenza. She was ill until March 1st, when she was well enough to get up but found she had no power in the legs. Shortly after this the legs became flexed upon the thighs and the thighs upon the abdomen. This has been the condition for most of the time since, the muscles becoming relaxed only when the patient is asleep or very quiet. The

bowels and bladder have been voluntarily controlled, micturition being frequent, about four times at night, five times during the day. The bowels are constipated, not moving sometimes for a week. About one month ago the movements of the bowels as well as micturition became involuntary. This lasted up to two weeks ago, when the involuntary condition ceased but the movements became frequent. Her mind has been clear all along. There has been no trouble with the eyesight, no pain in the head, and no pain in the back. The floor feels like a cushion. The upper extremities have at no time been affected. There is no cough at present.

Physical Examination.—Rather thin but generally fairly well developed colored girl. Somewhat pale. Tongue covered with a white coat. Pupils equal. No nystagmus. Movements of the eyes normal. Chest is rather flat; costal margin is prominent in right parasternal line. Over the upper right chest is a wound situated nearer sternum than axilla, measuring 5x2.5 cm. In the centre of this wound is a sinus in which a probe inserted passes upwards and inwards about 3 cm. to dead bone. Dead bone evidently in the sternum. Probe also passes behind sternum.

Lungs.—Front: Expansion very poor on both sides. Percussion fairly good. Breath sounds clear over right front. Slightly tubular in apex of right axilla. No râles are heard.

Back: Impaired resonance over both upper backs. At the left apex, breath sounds are somewhat tubular. At the base, percussion note is better, but everywhere expiration is somewhat blowing, particularly in left axilla. In this region vocal fremitus is absent, and breath sounds, as well as voice sounds, are distant.

Right lateral decubitus: A distinct bulging can be seen in the left flank. It measures about 8x4 cm. On palpation it is distinctly fluctuating. Hypodermic needle inserted withdraws a thick, cloudy fluid which, on microscopic examination, is found to consist of broken down cells and granular debris.

There is no marked irregularity of the spine, and apparently no pain anywhere on firm pressure. No bed sores.

Heart.—Point of maximum impulse somewhat diffuse over fourth and fifth spaces from the sternum to nipple line. At the apex the sounds are clear. Soft systolic murmur in the second left space. Aortic area clear.

Abdomen.—Muscles held rigidly; spleen distinctly palpable.

Muscular Power and Sensation.—Muscular power in the arms good, flexors stronger than extensors. Reflexes present at elbow, but not so easily obtainable at wrist. Movements of the facial muscles fairly good. Legs are strongly flexed on thighs and thighs somewhat on abdomen. Almost constant clonus in muscles of left thigh. On attempting to straighten the legs, they are found quite spastic, and clonus is increased. Considerable wasting in the calf muscles, not so marked in the thighs. Patient cannot voluntarily flex the legs upon the thighs. When the legs are extended there is still slight clonus in left flank; not so much in the right.

Sensation markedly impaired. Sensations of heat and cold are almost entirely gone from the umbilicus down. Sensation of touch much impaired. There is a region of hyperæsthesia in the back, extending from a little above the ilia and stretching over the gluteal muscles.

The patient was operated on November 2, 1896. The lumbar abscess was incised and packed. The condition of the lower extremities did not improve. The patient gradually became weaker, and died February 13, 1897.

AUTOPSY.

The autopsy was made by Dr. Flexner February 14, 1897. The following notes have been extracted, by permission, from the protocol in the Pathological Laboratory:

ANATOMICAL DIAGNOSIS.—*Tuberculosis of the spine. Extradural exudate. Compression myelitis. Paraplegia. Tuberculosis of sternum. Intestinal tuberculosis. Paralysis of bladder. Pyo-cystitis, pyo-ureteritis, pyelitis, pyelo-nephritis, bronchitis. Lateral curvature of the spine to the left in lower part.*

Muscles of feet and legs apparently very much atrophied. Thigh muscles also atrophied, the right more than the left.

On the right side, the pelvis is apparently thrown forward and rotated inward. Crest of the ilium is prominent, and right extremities are rotated inwards. The face shows no emaciation, contours rounded, lower jaw protuberant. The dura covering the brain is moderately adherent to the skullcap. The superior longitudinal and lateral sinuses contain recent clots. Pia and arachnoid are normal. No visible tuberculosis in the pia.

The *spinal cord* in two distinct situations is the seat of an extra-dural infiltration. The first begins about 2 cm. below the lower edge of the cervical enlargement and extends for a distance of about 5 cm. downwards; it is composed of dense caseous infiltration which averages 4–5 mm. in thickness. The second one begins above the lumbar region and extends over it and below it; it is thicker than the upper, but of the same nature. Both completely infiltrate the subdural areolar tissue.

The cord corresponding to the caseous infiltration is, in the cervico-thoracic region, distinctly softened. The roots of the spinal nerves (motor and sensory) pass through the exudate.

The exudate in the lumbar region has not compressed the spinal cord.

Heart.—Slight fatty degeneration in the intima of the aorta just above the valves.

Lungs.—Emphysematous and œdematous. Pus in bronchi.

Kidneys.—Capsule congested. Beneath the capsule and throughout the kidneys are white areas about the size of miliary tubercles. The kidney substance is soft and œdematous. On section, the cortex is greatly swollen. Striæ obliterated. Mucous membrane of the pelvis and ureters is congested, and shows ecchymoses.

Bladder.—Enormously distended; contains thick pus. Walls thin.

Spleen.—Enlarged; substance soft on section. A few tubercles seen. Tubercles are occasionally met with in mesentery and omentum.

Intestines.—Swollen solitary follicles in the ileum with excavated centres. Ulcers near the valve, edges raised, surrounded by congested mucous membrane. Tubercles visible in the clear congested base.

Spine.—The bodies of the second, third and fourth thoracic vertebræ are eroded, softened, crumbly, and infiltrated with caseous pus. The transverse processes of the second and third

lumbar vertebræ are similarly affected. The bodies of these vertebræ are only superficially diseased, however, and this affection is in the locality of the extra-dural exudate. Sternum eroded. Manubrium and gladiolus can be separated.

Muscles of the Back.—Along the spinal column the muscles are invaded by irregular sinuses and collections of pus-containing caseous material.

METHODS OF EXAMINATION.

The spinal cord was immediately put in a mixture of equal parts of formalin (5 per cent.) and Müller's fluid. The brain, including the medulla, was put into 5 per cent. formalin.

Four slabs of tissue were taken from each segment of the spinal cord, two pieces across the entrance and exit of the nerve roots, and two pieces between the nerve roots, so that when, in the description, a certain segment is designated, a level between the nerve roots above and below the number of the segment mentioned is indicated. Of these four slabs, two pieces were used for Weigert's method and two for Marchi's method of staining, comparative information being thus obtained.

The degeneration of nerve fibres, as is well known, can be divided into two periods—that before and that after the absorption of the disintegrated myelin. The former corresponds to the breaking up of the myelin sheaths into fat droplets; these stain black in Marchi's fluid. The latter corresponds to the stage shown best by Weigert's method, in which there has been absorption of the myelin, and hyperplasia of the glia. Thus the method of Marchi shows those fibres which have only recently degenerated, while Weigert's method gives information regarding those that have been degenerated for some time. As will be seen later, the picture obtained by these two methods differed considerably in parts. In general, the Weigert method revealed the greater alterations in this case, owing to the length of time which had elapsed since the beginning of the compression.

The roots of the spinal nerves on both sides, to as low a level as the twelfth thoracic inclusive (excepting the fourth cervical pair, which were accidentally lost), were likewise stained separately by the Weigert and Marchi methods.

For a more exact study of the pathological changes, especially in the softened region, additional stains were used—hæmatoxylin and eosin, hæmatoxylin and carmine, Upson's carmine, Van Gieson's stain, and Mallory's stain. Good results were also obtained by counter-staining Marchi specimens with Upson's carmine.

FINDINGS ABOUT THE REGION OF COMPRESSION.

As the protocol of the autopsy states there were two areas of extra-dural tuberculous exudate. The upper area alone led to compression of the cord.

The region of compression extends between the eighth cervical and the fourth thoracic nerves, thus involving about three segments of the spinal cord.

With low amplification (10 diameters), a section across the upper part of this region shows that the cord has been compressed dorso-ventrally, much more on the right than on the left side. The outline of the gray matter is faintly preserved; the white funiculi contain many bands of sclerotic tissue, more marked in the dorsal funiculi. Many small holes in the tissue also occur here. About the middle of the site of compression the cord is much compressed laterally and broadened dorso-ventrally. The gray matter is much distorted, the ventral horns being greatly shrunken; the dorsal horns can be followed for only half their extent. The white matter shows much sclerotic tissue, the holes above mentioned and numerous dilated blood-vessels. In the region corresponding to the lower part of the lesion there is remarkable distortion of the spinal cord. In the ventral half a normal contour is approached, but the dorsal half narrows to a blunt point at the tip of the left dorsal horn. The ventral horns are much shrunken, the dorsal horns are united for the ventral half of their extent; they then separate at an angle of about 60°, the right horn being much curved. The white matter abounds in sclerotic tissue and holes; the dorsal funiculi are destroyed in their ventral halves, their place being occupied by the united dorsal horns.

General Appearances at the Site of the Compression. See Figs. XIII and XIV.

1. Although the disintegration of the white matter has been very extensive, numerous axis-cylinders staining deeply with acid fuchsin can be seen. The nerve fibres illustrate all stages of disintegration. Many are much swollen and of irregular shapes. Some are entirely devoid of myelin sheath. In other fibres the myelin sheath is still present, but the normal concentric rings are absent. In only a few fibres are the normal concentric rings preserved. Vacuoles are found in many of the nerve fibres. They occur in various parts of the myelin sheath, but are found especially just peripheral to the axis-cylinders.

The axones show various changes. Some are swollen and very irregular in shape. At times only part of the axis-cylinder stains, giving rise to bizarre appearances. Some of the axis-cylinders refuse to take on the stain, and the nerve fibres are represented by homogeneous feebly staining masses. Many of the fibres have disappeared, leaving holes to represent them. In Marchi specimens, counter-stained in Upson's carmine, the disintegrated myelin is represented by smaller and larger black balls.

2. The neuroglia is much increased in amount (Fig. XIII). It helps to yield the intense red color seen in all the specimens stained in carmine. It occurs in fine and coarse bands in the lower part of the region of compression, giving rise to the reticulated appearance of the white matter. It is also much proliferated in the gray matter in the middle region of the compression, the dorsal cornu having been converted into masses of sclerotic tissue. Here the ventral fissure is filled with dense connective tissue, and the sclerotic tissue in the white matter can be seen to radiate from this. Many neuroglia-nuclei are seen, some small and round, staining homogeneously with carmine, and surrounded by a small colorless area; others, larger, oval or irregular in shape and granular. Here and there, scattered in the network of neuroglia, are masses of ball-like material, which take on a slight pinkish color in specimens stained by Van Gieson's method. In some

of these there is seen an irregularly shaped nuclear-like body, which takes on a faint pink stain.

3. The blood-vessels are numerous throughout the white and gray matter and in the fissures of the cord. They are much dilated and packed with blood corpuscles. Their walls stain intensely red in carmine, and around them are aggregations of cells with round and polymorphous nuclei. These vessels, with their thickened walls, give rise to the coarse bands found at the upper part of the region of compression. There has been considerable hemorrhage at the lower part of the region of compression. Throughout the white matter are many extravasated red blood corpuscles. They are massed in large heaps in the dorsal funiculi along the periphery and next to the broken up dorsal cornu. Scattered in the white and gray matter, are numerous polymorphous nuclear leucocytes. The blood-vessels at this level are much dilated and are full of corpuscles, most of them red.

4. The ganglion-cells show various changes in the region of compression. At about the level of the first thoracic and eighth cervical segments many of the cells are swollen, their protoplasm staining a homogeneous pink color in carmine. There is no trace of the normal tigroid masses, although these are well seen in sections from areas both above and below the compressed portion. The nucleus in some of the cells is displaced to the edge of the cell, being almost colorless, but containing a deeply staining nucleolus. The cell outlines are not sharp, and the protoplasmic processes are not seen. At the level of the second thoracic segment, only a few distorted ganglion-cells are to be seen. In Marchi specimens, counter-stained in Upson's carmine, these stain a homogeneous pink color, and contain numerous small intense black granules. At the level of the third thoracic segment there are but a few indefinitely outlined cells devoid of Nissl bodies, but containing numerous black granules. At the level of the fourth thoracic segment the cells are again more numerous, but Nissl bodies are to be made out only in some, and in many the nucleus is displaced to the side of the cell.

5. There is a proliferation of the cells lining the central canal at the level of the first, second and third cervical nerves. The cells here are a couple of layers thick, in parts occluding the lumen of the tube. From the third to the sixth cervical segments, the lumen of the canal is patent and lined by a single layer of high columnar cells. From the sixth cervical segment down to the sacral cord there appears to have been proliferation of these cells most extensive about the region of compression, being several layers thick there. The lumen is occluded from the first to the fifth thoracic segments. The cells in the proliferative area have lost their columnar appearance.

6. The holes, which have already been mentioned, are found far above and below, but are much more numerous at the site of the compression. These holes have been described before by Krauss,* who attributes their occurrence, probably correctly, to the action of formalin on the tissues, which he thinks causes a contraction of the neuroglia. In this way, he says, using a 10 to 15 per cent. solution of formalin, the hardened cord has a honeycomb appearance. The fact that these holes are more numerous around the region of compression, in the present case, makes it evident that a softened condition of the cord aids a great deal in effecting this appearance. Some of these holes are empty, some are partly filled by the products of disintegration and absorption of the nerve tissue. The following types and variations of the contents of the holes may be mentioned.

In or about the centre of a hole is a round body containing a nucleus, which stains well in nuclear dyes, surrounded by clear, homogeneous, non-staining, small globules. They are seen in specimens stained by all the methods used. They are the familiar compound granular corpuscles. Variations of this type occur, the granules taking on in carmine and Van Gieson specimens a faint pink tinge, giving the protoplasm of the cell a homogeneous or somewhat reticulated appearance. Vacuolic areas occur in these. This variation may be due to dissolving out of the fat.

In sections prepared by all the methods (including Marchi specimens, counter-stained in carmine) there are seen in the holes, bodies, some the size and shape of axis-cylinders, others much larger and of irregular shapes, which stain homogeneously and deeply in carmine, eosin and acid fuchsin. They are the so-called corpora amylacea.

There are seen in Marchi and Weigert specimens in the holes, small black droplets and larger black balls.

With Van Gieson's stain some of the holes are seen to be filled with indistinct globules of various sizes, which take on a faint yellowish tinge. In Weigert specimens, counter-stained in Upson's carmine, these are seen more distinctly, and take on a blackish coloration.

The picture presented is that of a myelitis of some duration, showing in different parts of the lesion the forms of white and red softening. The most common of the microscopical appearances are well known; these consist in the disintegration of the myelin into fat droplets, swelling of the axis-cylinders, swelling and disintegration of the ganglion-cells, together with an inflammatory exudation and an infiltration with blood corpuscles. Some of the fat granule cells seen are characteristic. Corresponding with the long duration of the inflammation there has been an extensive proliferation of neuroglia, giving rise to interlacing fibrils and dense sclerotic tissue.

MICROSCOPIC EXAMINATION OF CERTAIN LEVELS ABOVE THE LESION.—ASCENDING DEGENERATION.

The appearance of a section at a given level varies with the method of preparation. In the following descriptions the method is indicated, and when the degeneration field at any one level varies according to different methods several sections will be described. The degenerated fibres are shown in specimens stained by Marchi's method, as black droplets of irregular contour, which on high magnification are seen to take the place of the myelin sheaths of the nerve fibres. The appearance varies according to the magnification used. Some degenerations are so clearly defined as to be readily studied with a magnification of 10 diameters; in others the degenerated

*Krauss, W. C. Formalin as a hardening agent for nerve tissues. Trans. Am. Micr. Soc., 1895, Buffalo, 1896, vol. xvii, pp. 331-335.

fibres are so few and scattered, as to require a higher magnification.

The degeneration field is indicated in the Weigert preparations by a lightening or lack of color. Where only a few scattered fibres have undergone degeneration, it is often impossible by Weigert's method to determine their absence.

First Thoracic Segment.—Upper part stained by Marchi's method and Upson's carmine.

The shape of the cord is tolerably well preserved here; the gray matter is of normal configuration, but is not very sharply marked off from the white substance.

Dorsal funiculi: These show degeneration over the whole cross-section, but not completely. The degenerated fibres are more closely aggregated in the ventral half, but even here there is much intervening matter, partly of a fibrous nature, which stains deeply with carmine. A few axis-cylinders are seen on the periphery. Throughout are many dilated blood capillaries.

Lateral funiculi: In the regions of the fasciculus cerebrospinalis lateralis (lateral pyramidal tract) and the fasciculus cerebellospinalis (direct cerebellar tract) are seen scattered degenerated fibres. The zone thus occupied does not quite reach the lateral horn of the gray matter. Neuroglia tissue is found between the degenerated nerve fibres, and throughout, but more numerous towards the periphery, are large holes, some empty, some filled with material, as before described. But few axis-cylinders are found, staining a bright red color. Extending ventralward from the region of the fasciculus cerebellospinalis is a marginal strip, reaching the ventral median fissure, containing a few degenerated fibres, the number being more numerous in front.

Eighth Cervical Segment.—Weigert-Pal preparation. The shape of this section closely resembles that of the last.

Dorsal funiculi: Seen by the naked eye the dorsal funiculi appear much lightened throughout, excepting a narrow strip on the periphery stretching between the tips of the dorsal gray horns. Microscopically, the degeneration is confirmed. One sees numerous minute holes, probably representing degenerated dorsal root fibres, greatest in extent along the middle third of the septum. Throughout, however, are found numerous well-stained fibres, and along the periphery they all appear of a normal color.

Lateral funiculi: Here the lightened or degenerated area occupies the peripheral half of the column, extending from the tip of the dorsal gray horn to opposite the lateral gray horn. Many holes appear in this region. No lightening occurs in the fasciculus ventrolateralis superficialis (Gowers' tract).

The Marchi specimens show degenerated fibres in practically the same areas in the dorsal funiculi. In the lateral funiculi degenerated fibres are scattered in the peripheral half, being very scattered in the fasciculus ventrolateralis superficialis.

Seventh Cervical Segment, Weigert-Pal preparation. See Fig. VIII.

Dorsal funiculi: The degenerated area no longer occupies the whole breadth of the dorsal funiculi. A relatively large area of healthy fibres intervenes between it and the dorsal gray horn. Considering both sides of the degeneration together, the lightened area has the shape of a tennis racquet, the end of which next the dorsal gray commissure is slightly expanded. As at the preceding level, the majority of the degenerated fibres occur along the ventral half of the septum.

Lateral funiculi: The lightened area, less intense than in the dorsal funiculi, extends from the tip of the dorsal gray horn to the emergence of the ventral roots. In its dorsal part it occupies the lateral third of the lateral column; in the region of Gowers' tract it is slightly broader, occupying about half the breadth of the column. The lightening seems to consist in a feebleness rather than a lack of staining. Between Gowers' tract and the direct cerebellar tract is a band of fibres staining more deeply.

The Marchi specimen shows a similar distribution of the degenerated fibres in the dorsal funiculi, with a few scattered degenerated fibres in the lateral part of the fasciculus cuneatus (Burdachi). In the lateral funiculi, there are but scattered degenerated fibres in the lateral pyramidal tract, direct cerebellar tract, and Gowers' tract; they are most numerous at the periphery of the cord.

Fifth Cervical Segment, Weigert preparation. See Fig. VII.

Dorsal funiculi: The degenerated area occupies now a little more than the fasciculus gracilis. Considering both sides together it is bottle-shaped, the part resting next the dorsal gray commissure being slightly expanded. The lightening is more marked in the ventral half.

Lateral funiculi: The degenerated area extends from the tip of the dorsal horn to the exit of the ventral root. Next the dorsal horn, it occupies the peripheral third of the lateral column for a short distance; it then narrows, and opposite the lateral gray horn it again expands, occupying half the breadth of the column.

Marchi specimens stained in carmine show a marked increase in neuroglia among the degenerated fibres in the dorsal fasciculi. Here also are seen many axis-cylinders staining intensely red. Burdach's fasciculus contains a few scattered degenerated fibres. In the lateral column the degenerated zone is about the same shape as in the Weigert specimen, the direct cerebellar being more affected. In the region of the fasciculus ventrolateralis superficialis (Gowersi), the degenerated fibres are more scattered.

Third Cervical Segment, Weigert preparation. See Fig. V.

Dorsal funiculi: The lightened area is restricted to the fasciculus gracilis (Golli), occupying the dorsal three-fourths. Considering both sides together the area is triangular in shape with the base at the periphery. There is a small peripheral part next the dorsal median septum which is scarcely at all lightened.

The entering dorsal roots on both sides show lightening, more marked on the right side. There is also lightening of Lissauer's fasciculus.

Lateral funiculi: The degenerated zone extends from the tip of the dorsal gray horn to the ventral roots, occupying the peripheral half of the lateral column. It is much more intense in Gowers' tract. In the region of the fasciculus cerebellospinalis (direct cerebellar tract) the degeneration is

more marked a little inwards from the periphery of the cord. Next the periphery there is a band of almost normally staining fibres. Notwithstanding the degenerated fibres in the dorsal roots, the collaterals entering the gray matter appear to be of normal number and to be well stained.

The Marchi specimen (Fig. VI) shows in addition to the triangular area in Goll's fasciculus scattered degenerated fibres in the fasciculus cuneatus, more numerous on the periphery.

In the lateral funiculi it is to be especially noted that more degenerated fibres are visible in the fasciculus cerebellospinalis (direct cerebellar tract) than farther ventralwards. The degeneration of this tract is better defined here than in the sections lower down.

Second Cervical Segment, Weigert preparation. See Fig. III.

In the dorsal funiculi the degeneration is the same as that described for the third cervical segment.

In the lateral funiculi the fasciculus cerebellospinalis and the fasciculus ventrolateralis superficialis are degenerated in about the same region as seen at the third cervical segment; the band of more deeply staining fibres along the periphery next the fasciculus cerebellospinalis is very well marked. Besides these degenerations there appears to be a slight lightening in the lateral funiculi extending along the outside of the lateral gray horn. It is not very marked, and blends with the area of healthy fibres separating it from the fasciculus of Gowers.

The Marchi specimens (Fig. IV) at this level show blackened fibres in the entering dorsal roots.

First Cervical Segment, Weigert preparation. See Fig. I.

Dorsal funiculi: A surprising change has occurred in the shape of the degenerated field. Considered as before, the triangle has lengthened dorso-ventrally, the apex again reaching the dorsal gray commissure. The shape is not strictly triangular, as there is a slight concavity on each side next the fasiculus cuneatus (Burdachi). The dorsal half of the area is not as much lightened as the rest.

Many unstained fibres are seen in the dorsal roots on both sides. Lissauer's fasciculus also shows considerable lightening.

Lateral funiculi: Here the degenerated zones are separated a little ventral from the tip of the dorsal horn by a band of less lightened tissue. The dorsal portion embraces Lissauer's fasciculus, and is separated from the periphery by a narrow strip of almost normally staining white matter. The ventral part starts a little behind a line drawn across the lateral gray horns, and extends to the emergence of the ventral roots, occupying the lateral half of the column. There is also a slight lightening next the lateral gray horn.

The Marchi specimen (Fig. II) from this segment represents a little higher level, namely, at about the lowest part of the decussation of the pyramidal tract.

In the dorsal funiculi a few degenerated fibres are seen on the dorsal periphery of the fasciculus cuneatus.

The degeneration in the fasciculus cerebellospinalis is well marked, the shape of the area differing slightly from that last described, being much thickened next the tip of the dorsal gray horn. In the region of the fasciculus ventrolateralis superficialis there are but few scattered degenerated fibres.

MICROSCOPIC EXAMINATION OF CERTAIN LEVELS BELOW THE LESION.—DESCENDING DEGENERATION.

Fourth Thoracic Segment, Marchi specimen. See Fig. IX.

The entire degeneration is so distinct that the individual degenerated fibres can be seen with a magnification of ten diameters.

Dorsal funiculi: The degeneration assumes a peculiar shape, which may be considered as a union of a septal degeneration and a degeneration of the comma of Schultze. The former begins at a point on the dorsal median septum and running ventralwards broadens out to join the comma tract. The latter is separated by a narrow interval from most of the dorsal horn, but touches the dorsal gray commissure and the nucleus dorsalis (Clark's column), where it is broadest. From here it tapers off going dorsalwards, extending about three-fourths of the distance between the commissure and the periphery in the fasciculus cuneatus. The degeneration though intense is not complete.

Lateral funiculi: The fasciculus cerebrospinalis lateralis contains many degenerated fibres, and also many holes as described before. Some degenerated fibres appear on the periphery in the region of the fasciculus cerebellospinalis. Besides these, there is a small zone of scattered degeneration in the fasciculus lateralis proprius, next to the pyramidal tract.

The ventral funiculi contain scattered degenerated fibres. Numerous holes appear in the ventral and lateral funiculi, being more abundant along the periphery.

In the Weigert specimen, the degeneration occupies practically the same area. The comma zone is more lightened than the area of septal degeneration in the dorsal funiculi.

Fifth Thoracic Segment, Weigert preparation. Fig. X.

Dorsal Funiculi: There is a narrow degenerated strip in the fasciculus cuneatus, beginning near the gray matter constituting the nucleus dorsalis (Clarkii) and extending dorsalwards half the breadth of the fasciculus. The lightening is plainly visible, but not intense.

In the lateral funiculi, there is typical degeneration of the fasciculus cerebrospinalis lateralis (lateral pyramidal tract).

Marchi Specimen: No blackened fibres are seen in the dorsal funiculi. The pyramidal degeneration occupies the same area as that in the Weigert preparation. In the ventral funiculi, there are a few scattered fibres extending from the ventral median fissure to the emergence of the ventral roots, occupying the lateral half of the funiculus.

Sixth Thoracic Segment, Weigert specimen. See Fig. XI.

It is to be noted that the strips of degeneration in the dorsal funiculi are seen for the last time at this level.

From this point on the pyramidal tract degenerates in its well known form, being restricted at the beginning of the intumescentia lumbalis to the lateral two-thirds of the lateral funiculus. Here it is separated from the gray matter by a band of sound fibres.

SUMMARY OF THE ASCENDING DEGENERATION.

1. *Dorsal Funiculi.*—Starting at the level of the first thoracic segment the degenerated area occupies the whole of the dorsal funiculi but is not complete. Some fibres particularly on the periphery are spared. Traveling up, the degenerated area is narrowed by the entering dorsal roots, so that at the level of the seventh cervical segment it assumes the shape of the tennis racquet before described; at the level of the fifth cervical segment it is bottle-shaped, occupying now little more than the region of the fasciculus gracilis (Golli). It is to be noted in comparing the Weigert-Pal and Marchi specimens that the parts shown to be most sclerosed by the former method, namely, the ventral and medial parts, show by the latter a lessened number of blackened myelin sheaths; whereas the blacker parts in the Weigert's specimens, the dorsal part, show some blackened sheaths. In general, the distribution of the degeneration, as shown by the two methods, is the same. At the level of the third cervical segment the degenerated area is triangular in shape, occupying the dorsal three-fourths of the fasciculus gracilis. At the first cervical segment the degenerated triangle has lengthened dorso-ventrally, again reaching the dorsal gray commissure. In the medulla, the fasciculus gracilis is much degenerated, and the degenerated fibres can be followed directly into the nucleus funiculi gracilis.

Besides this typical ascending degeneration, there is to be seen in the Marchi specimens, at the level of the first, second and third cervical segments, a narrow marginal degeneration in the fasciculus cuneatus. Farther down at the fourth and fifth cervical segments a few degenerated fibres are seen in this region. It is also to be noted that the dorsal roots at the level of the first, second and third cervical segments are partially degenerated.

2. *Fasciculus Cerebellospinalis* (*Direct Cerebellar Tract*).—The degeneration of this fasciculus corresponds to a definite area at the level of the eighth cervical segment. Below, the degenerated fibres of this fasciculus are mingled with those of the lateral pyramidal tract and of the fasciculus lateralis proprius. At the lower part of the eighth cervical segment it occupies the lateral half of the lateral column, extending as far forward as a point opposite the lateral gray horn. In ascending, the area of this degeneration, as seen in the Weigert preparations, remains narrow in its dorsal half, broadening out a little dorsal to the lateral gray horn, where it joins the fasciculus ventrolateralis superficialis (Gowersi.) (In the Marchi specimens the zone remains narrow until it reaches the lateral gray horn.)

The shape has completely changed at the level of the third cervical segment. For a short interval in front of the tip of the dorsal horn it is very narrow, it then broadens, and is compact and well marked midway between the dorsal and lateral gray horns. At this level there is a zone of darker staining fibres next to the periphery in the Weigert specimen, a little ventral to the tip of the dorsal gray horn. The Marchi specimen shows a well defined degeneration there. Ascending, the degeneration lessens very much in the Weigert specimens. At the first cervical segment, a sound band of fibres is interposed between the periphery and the degenerated area, as seen in the Weigert specimens. Here the degenerated area consists of a small part projecting from the tip of the dorsal horn, and separated from the periphery by the band of sound fibres mentioned. In the Marchi specimen at this level the relations are very different from those met with in the Weigert preparations; the degenerated area, which is very well defined, is very broad next the dorsal horn, and narrows to a point as it extends ventralwards. This latter shape is preserved at the lower part of the medulla, as seen in the Marchi specimens.

3. *Fasciculus Ventrolateralis Superficialis* (*Gowersi*).—The description of this fasciculus corresponds to the Weigert specimens, as the degeneration of this tract is not well marked in the specimens prepared by the method of Marchi. The degeneration is first plainly visible at the lower part of the seventh cervical segment, where it extends from the direct cerebellar tract to the emergence of the ventral root. It occupies here the peripheral half of the lateral funiculus, but is not very well marked at this level. Ascending it undergoes but slight change in shape. At the third cervical segment it becomes more intense, and is separated from the direct cerebellar tract by a band of darker color (less degenerated). This relation is seen also at the first cervical segment.

SUMMARY OF DESCENDING DEGENERATION.

1. *Fasciculus Cerebrospinalis Lateralis* (*Lateral Pyramidal Tract*).—The degeneration in this tract begins at the fourth thoracic segment, where it is well marked, and is slightly removed from the neck of the dorsal horn. Descending it becomes smaller, the interval between it and the dorsal horn becoming widened. Corresponding to the change in shape of the cord in the lumbar region, it becomes narrowed from side to side and broadened dorso-ventrally. The degeneration continues down to the conus terminalis; at the lower sacral region it can be plainly seen in the Weigert specimens, but it is no longer sharply outlined.

2. *Fasciculus Ventralis Proprius and Fasciculus Lateralis Proprius* (*Ventrolateral Ground Bundles*).—The degeneration in the ground bundles is most evident in the Marchi specimens. It begins at the level of the fourth thoracic segment, where it occupies the entire ventral and part of the lateral funiculus. It rapidly diminishes in size, and has entirely disappeared at the level of the seventh thoracic segment.

3. *Septal Degeneration.*—This is an intense degeneration extending along the dorsal median septum from the dorsal gray commissure to near the periphery of the cord. It can be made out in Weigert specimens for but one segment below the lesion.

4. *Comma of Schultze.*—This is seen beautifully at the level of the fourth thoracic segment, one segment below the lesion. The head of the comma almost touches the dorsal commissure, and joins on the other hand the septal degeneration before described. The head is more intensely degenerated than the tail end, which does not reach the periphery of the cord. At the level of the fifth thoracic segment, the degenerated areas occupy two small strips in the fasciculus cuneatus reaching to the gray matter. The tract is last seen as a similar less intense degeneration at the sixth thoracic segment.

COMPARISON OF THIS CASE WITH OTHERS IN THE BIBLIOGRAPHY.

A feature of this case, very little described and figured in the literature, is the appearance of the holes left empty by the degenerated nerve fibres. The peculiar pictures seen are to be regarded, in general, as different stages in the disintegration of the nerve fibres. V. Babes* describes and figures some of these, namely, the hyaline masses occupying part of the holes. He says that the latter are probably derived from swollen axis-cylinders. The study of the present case confirms this view, as all stages between the degenerating fibres and the hyaline masses can be seen. He also pictures the holes, which are, in his cases, entirely filled with fat droplets.

E. A. Homén,† in Babes' Atlas, describes the process of the degeneration of the nerve fibres as it occurs experimentally in dogs. According to him, the first change to take place occurs about four days after the lesion, and consists of a swelling and granulation of the axis-cylinders. These lose their power of staining with the usual dyes, but stain strongly with acid fuchsin. This, according to Homén, harmonizes with the theory which assumes the cell to be the trophic centre, since the axis-cylinder is the first to suffer from the disconnection of the nerve fibre with it. This statement differs from that of Müller. Müller‡ noted in a case of myelitis of tuberculous origin, that certain axis-cylinders colored deeply in specimens stained by Van Gieson's method; he found further that the myelin sheaths, corresponding to these intensely staining axis-cylinders, are those which stain by Marchi's method. He takes this as evidence of the strong vitality of the axis-cylinders, and says that they can withstand destructive influences for a longer time than the myelin sheaths. In the present case, many deeply staining axis-cylinders were seen about the site of compression in sections stained by Van Gieson's method. In specimens stained both by Marchi's and Van Gieson's methods, some of the axis-cylinders in the degenerated fibres refuse to stain, and others stain but feebly.

The changes in the axis-cylinder are followed by a fragmentation of the myelin sheath, which begins in the part of the myelin immediately adjacent to the axis-cylinder and extends peripheralwards (Homén). This harmonizes with the fact that in the present case vacuolar areas were frequently found surrounding the axis-cylinder. In ten or twelve days the fibres first affected are, Homén declares, broken up into a granular mass. About this time, or a few days later, there begins to be a reaction on the part of the neuroglia, manifested by karyokinesis and proliferation of the neuroglia cells. About the twenty-first day, the corpora amylacea first appear. About the same time a few leucocytes and compound granular cells are met with.

Dorsal Funiculi.—This case confirms and adds to the history of secondary degenerations in this region. The ascending and descending degenerations concern fibres of both exogenous and endogenous origin. It has been long known that the fibres of exogenous origin after entering the dorsal funiculi bifurcate; the long ascending limbs of bifurcation are displaced so as to occupy a position more medial and dorsal as they pass up. Thus, a compression in the lower region of the cord causes an area of degeneration in the dorsal funiculi, which in ascending becomes gradually smaller in size, assuming in the cervical region a triangular shape with the base of the triangle at the periphery of the cord. The peripheral distribution of this and other long tracts led Flatau* to formulate the law "that the short fibres of the cord run in close relation to the gray matter, while the long fibres select a position nearer to the periphery of the cord."

What is exceptional in the present case is the fact that the apex of the triangular shaped degeneration does not reach the dorsal gray commissure at the level of the third cervical segment, whereas higher up in the region of the first cervical segment it has become lengthened dorso-ventrally, again reaching the dorsal gray commissure. In Schultze's† cases, in two of which the lumbar cord was diseased, in one the cauda equina affected, and in the other there was a complete transverse lesion of the lower thoracic region, this dorso-ventral lengthening of the degenerated area was not seen. It is not pictured by Gombault and Philippe.‡ It is shown, however, in a case of Darkschewitch's,§ in which the cauda equina was pressed upon by a pachymeningitis. In his case the dorso-ventral lengthening was pictured high up in the cervical cord. The apex of the degenerated triangle in the fasciculus gracilis, in Spiller's‖ case, in which the compression was exerted at the cervico-thoracic junction of the cord, did not reach the dorsal gray commissure in a section taken just below the pyramidal decussation.

Concomitant with this dorso-ventral lengthening of the degenerated area, we find degenerated fibres in the dorsal roots of the first, second and third cervical nerves. The question naturally arises, is there any connection between these two facts. That this lengthening of the degenerated area is due to these degenerated dorsal root fibres is negatived both by the result of section of the cervical dorsal roots and

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*Babes, V. Verschiedene Formen der Entartung und Entzündung des Rückenmarkes. Atlas d. path. Histol. d. Nervensyst. Berl., 1896, Lfg. vi, S. 20-35.

†Homén, E. A. Die histologischen Veränderungen bei der (experimentellen) secundären Degeneration des Rückenmarkes. Atlas d. path. Histol d. Nervensyst. Berl., 1896, Lfg. vi, S. 5-19.

‡Müller, L. R. Ueber einen Fall von Tuberculose des oberen Lendenmarkes mit besonderer Berücksichtigung der secundären Degenerationen. Deutsche Ztschr. f. Nervenh., Leipz., 1896-7, Bd. x, S. 273-291.

*Flatau (E.) Das Gesetz der excentrischen Lagerung der langen Bahnen im Rückenmark. Ztschr. f. klin. Med., Berl., 1897, Bd. xxxiii, S. 55–152.

†Schultze. Beitrag zur Lehre von der secundären Degeneration im Rückenmarke des Menschen nebst Bemerkungen über die Anatomie der Tabes. Arch. f. Psychiat., Berl., 1883, Bd. xiv, S. 259-390.

‡Gombault, A. et Philippe. Contribution a l'etude des lésions systématisées dans les cordons blancs de la moelle épinière, Arch. de méd. expér. et d'anat. path., Par., 1894, t. vi, H. 365-424.

§Darkschewitsch, L. O. Zur Frage von den secundären Veränderungen der weissen Substanz des Rückenmarks bei Erkrankung der Cauda equina. Neurol. Centralbl., Leipz., 1896, Bd. xv, S. 5-13.

‖Spiller, W. G. A microscopical study of the Spinal Cord in two cases of Pott's Disease. Johns Hopkins Hospital Bulletin, Balt., June, 1898.

the study of human cases, in which either the cervical roots were degenerated or there was a lesion of the upper thoracic or cervical cord; these results teach us that the ascending branches of the cervical dorsal roots remain throughout their entire course in the funiculus cuneatus. That the degenerated fibres are not longitudinal association paths seems untenable in light of the case reported by Mme. J. Dejerine and J. Sottas* of medullary syphilis of the cord, extending from the third to the eleventh thoracic roots. The authors found the fasciculus gracilis entirely degenerated, and they concluded from this and other cases that the fasciculus gracilis is composed entirely of ascending dorsal root fibres, and that it does not receive in its course any fibres of endogenous origin. The dorso-ventral lengthening of the degenerated area is readily understood, if the view that some fibres of the fasciculus gracilis end in the gray matter of the upper cervical region is correct.

Comma of Schultze.†—Our knowledge concerning the endogenous paths in the cord is not so satisfactory. The path, known as the comma of Schultze, had been seen as early as 1866 by Bouchard, and later by Strümpell, but it was first made the object of especial study by Schultze in 1883. Among several cases of degeneration in the spinal cord from compression, he found the comma shaped area in only one instance, extending as two parallel lines, two and one-half centimeters below the lesion.

The origin of the fibres in Schultze's comma is still a disputed point. Schultze assumed that they came from the dorsal roots, and the same view has been held by Bruns, Lenhossék, Singer and others. Gombault and Philippe, Tooth, Marie and others maintain that they do not come from dorsal root fibres, as the comma is found degenerated in lesions of the cord itself. It is to be noted, however, that dorsal root fibres, that have already entered the cord, or their descending limbs of bifurcation, might be involved in a lesion of the cord itself.

That degeneration of the comma tract is, in this instance, not due to lesions of the dorsal roots outside the cord is proved by the present case, where all the root fibres are perfectly healthy for no less than eight segments above and for all the segments below the lesion. The fibres must arise then from the tracts in the ventral or lateral funiculi of the cord, from descending fibres of the dorsal roots which have already entered the cord, or from the cells of the cord. Now, as a matter of fact, no one has seen or imagined the least connection between the tracts in the lateral and ventral funiculi and the comma tract, or between the ventral roots and the comma path. Against the view that the bulk of the path is constituted of descending limbs of bifurcated dorsal root fibres is its long course, since, as shown by Hoche, degenerated fibres of the comma tract may be traced for ten segments below the site of the lesion, while it is generally believed that the descending branches of the dorsal root fibres run down but a short distance (von Lenhossék). The bulk of the path is then, in all probability, made up of fibres which arise in cells situated in the gray matter of the cord, a view which is made all the more probable by the close relation which has been proven to exist between this path and the gray matter.

Within the last year there has appeared an article by Zappert, in which he supports the view that the path is composed of fibres partly of exogenous and partly of endogenous origin. He studied the cord of a luetic child which had died a few days after birth. There was inflammation of the pia mater in the cervical region, compressing the ventral and dorsal roots in this region and causing their degeneration. The cord itself was intact. Besides other degenerations, he found an intense degeneration of the comma of Schultze, reaching as far as the lower third of the thoracic cord. He therefore believes that the greater part of Schultze's comma is made up of fibres of exogenous origin.

The path is now recognized as a long path. Schultze, as mentioned, found it for only a short distance below the lesion. In the present case it was seen but for three segments below the lesion, probably because the Weigert method is not delicate enough to demonstrate the sparsely scattered degenerated fibres lower down. Hoche, Bruce and Muir, and others, by means of Marchi's method, in cases of recent injury, have proven conclusively that the path extends for ten or more segments below the lesion; in one case Hoche followed it down into the lumbar cord, although below, the fibres were very scattered.

The method used, and the fact that the authors did not follow the degeneration closely enough, led to the erroneous view of Gombault and Philippe, who thought that the comma tract was connected with the oval field of Flechsig. They explained the change in position by saying that higher up the oval-field fibres are pushed aside, in a way analogous to the formation of the fasciculus gracilis.

The fibres of Schultze's comma probably end, as pointed out by Hoche, in the gray matter of the dorsal horn, as they re-

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* Dejerine, J., et J. Sottas. Sur la distribution des fibres Endogènes dans le cordon postérieur de la moelle et sur la constitution du cordon de goll. Comp. rend. Soc. de biol., Par., 1895, 10 s., t. ii, pp. 465-469.

† The following bibliography dealing with the comma of Schultze has been consulted: —

Schultze. Beitrag zur Lehre von der secundären Degeneration im Rückenmarke des Menchen nebst Bemerkungen über die Anatomie des Tabes. Arch. f. Psychiat., Berl., 1883, Bd. xiv, S. 359-390.

Gombault et Philippe. Contribution a l'etude des lésions systématisées dans les cordons blancs de la moelle épinière. Arch. de méd. expér. et d'anat path., Par., 1894, t. vi, pp. 365-424.

Lenhossék, M. v. Der feinere Bau des Nervensystems im Lichte neuester Forschungen. Berl., 1893.

Hoche, A. Ueber Verlauf und Endingungsweise der Fasern des ovalen Hinterstrangsfeldes im Lendenmarke. Neurol. Centralbl., Leipz., 1896, Bd. xv, S. 154-156.

—— Also, Ueber secundäre Degeneration, speciell des Gowers'-chen Bündels, nebst Bemerkungen über das Verhalten der Reflexe bei Compression des Rückenmarkes. Arch. f. Psychiat., Berl., 1896, Bd. xxviii, S. 510-543.

Zappert, J. Beiträge zur absteigenden Hinterstrangsdegeneration. Neurol. Centralbl., Leipz., 1898, Bd. xvii, S. 103-107.

Müller, L. R. Ueber einen Fall von Tuberculose des oberen Lendenmarkes mit besonderer Berücksichtigung der secundären Degeneration. Deutsche Ztschr. f. Nervenh., Leipz., 1896-7, Bd. x, S. 273-291.

Campbell, A. W. On the Tracts in the Spinal Cord and their Degenerations. Brain, Lond., 1897, vol. xx, pp. 488-535.

Spiller, W. G. A Microscopical Study of the Spinal Cord in two Cases of Pott's Disease. Johns Hopkins Hospital Bulletin, Balt., June, 1898.

remain next to it for their entire course. He was able to trace fibres for a short distance into the gray matter, but they were soon lost owing probably to a change in direction.

The septal degeneration which runs but one segment below the lesion is rather unusual. Hoche figured it somewhat as seen in the present case. Spiller, in a case of compression of the cord at the level of the first thoracic segment, found a diffuse degeneration of the ventral portion of the dorsal funiculi, which extended 3½ cm. below the place of compression. Müller also described an intense degeneration of the ventral half of the dorsal funiculi, which extended for several segments below the compression, which was due to a solitary tubercle of the spinal cord, extending between the first and second lumbar nerves.

Fasciculus Cerebellospinalis.—Of the views relating to the origin of the axones of this path, that most generally accepted is that they arise from the nerve cells of the nucleus dorsalis. Tooth* however concludes from his experimental work done on monkeys, that in the cervical region and possibly also in the upper thoracic region, fibres from the dorsal roots of the spinal nerves enter largely into the composition of this tract. Tooth admits that lower down the fibres do not come by way of the dorsal roots. If this view of Tooth is correct, it will possibly explain the different pictures of this path, in the present case, given by the methods of Marchi and Weigert.

The nucleus dorsalis, which then, everyone admits gives rise to the bulk of this fasciculus, extends from the seventh cervical to the third lumbar segment of the spinal cord. The lowest limit of the transverse lesion in this case, being at the level of the third thoracic segment, one would expect an extensive involvement of this tract. The degeneration of this tract is found to occupy in its lower part, the usual area ascribed to it, but it is not very intense. The interesting point in connection with it is the variation in the picture given by the method of Marchi from that revealed by the method of Weigert.

Up to the third cervical segment, as seen by both methods, the degenerated area occupies its usual position, extending ventralwards from the tip of the dorsal gray horn and outside the region of the fasciculus cerebrospinalis lateralis. At the level of the third cervical segment the field degenerated becomes more evident in the Marchi specimens. It will be remembered that the third cervical dorsal roots on both sides are degenerated. The view of Tooth, that the cervical dorsal roots take part in the formation of this fasciculus, would explain this tract becoming more evident here. If Tooth be correct, however, it is curious that such a host of observations as those recorded, have been constantly negative as regards this point. On the other hand, in the Weigert specimen, the intensity of the degeneration remains the same, and there appears a band of sounder fibres which lies on the periphery of the cord next to the tip of the dorsal gray horn. The third cervical roots as seen in the Weigert specimen also contain degenerated fibres. At the level of the first cervical segment the area of degeneration is very faint in the Weigert specimens, and is separated from the periphery of the cord by a bundle of sound fibres. On the other hand, in the specimens prepared by the method of Marchi, the degeneration is very well marked. It is readily seen with a magnification of ten diameters. The first and second cervical dorsal roots are found degenerated by both methods. The shape of the degeneration, also, is somewhat different at the level of the first cervical segment in the Marchi specimens. Next to the tip of the dorsal gray horn it is very broad, occupying the peripheral third of the lateral column. In passing ventralwards it diminishes in breadth.

The shape of this tract as seen in the Marchi specimens corresponds to that in the new edition of Quain* in a case of hemi-section at the level of the twelfth thoracic nerve. Hoche's† pictures of this tract at the level of the first cervical segment do not correspond with that seen in the present case. His cases were instances of compression myelitis at the level of the first thoracic and between the fourth and fifth thoracic segments. He represents the fasciculus cerebellospinalis as starting in a point at the tip of the dorsal gray horn and increasing in width on going ventralwards to join Gowers' tract. In his cases the cord was examined from four to six weeks after the onset of compression.

Fasciculus Ventrolateralis Superficialis (*Gowersi*).—This tract is not so well understood as is the direct cerebellar. Its origin is not definitely known. Schäfer in Quain's Anatomy states that it probably comes from cells in the dorsal horn in the lumbar region. Campbell‡ believes that the axones probably arise from cells in the gray matter of the lumbar cord, possibly in the "middle cell-column" of Waldeyer. Lenhossék§ says it arises partly from cells in the ventral horns and partly from cells in the middle zone of the gray matter.

One would therefore expect in this case to find considerable degeneration of this tract. This is not especially indicated in either the Weigert or Marchi specimens. In the latter only scattered degenerated fibres are found in the tract as far up as it was traced. The Weigert method revealed more alterations, and with it the degeneration seemed to be more intense at the higher levels of the cord. It was not, as mentioned by Schäfer, most intense immediately adjacent to the fasciculus cerebrospinalis lateralis (lateral pyramidal tract), but a little ventral to this, opposite the gray horn. This appearance comes out best at the first cervical segment, where a sounder band of fibres is interposed between the degenerated Gowers' tract and the direct cerebellar tract.

The position of Gowers' tract in the figures of Hoche agrees fairly well with the present case as far as the first cervical seg-

*Tooth. Quoted from A. W. Campbell, Brain, 1897, op. cit. p. 8.

*Quain (J.) The Elements of Anatomy. Edited by E. A. Schäfer and G. D. Thane. 10 ed. The Spinal Cord and Brain, 1893.

†Hoche, A. Ueber secundäre Degeneration, speciell des Gowerschen Bündels, nebst Bemerkungen über das Verhalten der Reflexe bei Compression des Rückenmarkes. Arch. f. Psychiat., Berl., 1896, Bd. xxviii, S. 510-543.

‡Campbell, A. W. On the Tracts in the Spinal Cord and their Degenerations. Brain, Lond., 1897, vol. xx, pp. 488-535.

§Lenhossék, M. v. Der feinere Bau des Nervensystems im Lichte neuester Forschungen, Berl., 1893.

ment, the difference of methods being taken into consideration. Farther up the degeneration cannot be followed in the Weigert preparations, nor is it indicated in the Marchi specimens. It is generally conceded that the bulk of Gowers' tract is ascending, so the fact that the degeneration of the direct cerebellar comes out well, and that of Gowers poorly or not at all, by Marchi's method, would seem to indicate that Gowers' tract degenerated sooner in this case than the direct cerebellar.

Rapidity of Degeneration.—It may be worth while here to say a word concerning the results given by the Weigert and Marchi methods. Schaffer* noted certain differences between the results of the two methods in a case of transverse lesion of the spinal cord. He employed both the Marchi and Weigert methods, and obtained results which differed from previous observations. He concluded from his work that after a transverse lesion of the cord, the fasciculus gracilis degenerates most quickly, the fasciculus cerebrospinalis lateralis next, while the descending degeneration in the dorsal funiculi, the ascending degeneration of the fasciculus cuneatus, the fasciculus ventrolateralis superficialis and the fasciculus cerebellospinalis follows later.

Whether all of Schaffer's conclusions are true or not remains to be seen, but the case here recorded lends support to some of his statements. The fasciculus gracilis is the most sclerosed of all the tracts, as is beautifully revealed by Weigert's method. Homén† states that after section of the spinal cord in dogs, the first degenerative changes are seen three or four days after the operation in the dorsal funiculi above the place of operation. The fasciculus cerebrospinalis lateralis shows on the whole slightly more degeneration by Weigert's method than either the fasciculus cerebellospinalis or the fasciculus ventrolateralis superficialis, although the latter shows well marked degeneration at the highest levels of the cord. The Marchi method which reveals degeneration in actual progress, shows least of all in Gowers' tract throughout its entire course. The degenerated field in the dorsal funiculi corresponds in area to that in the Weigert specimens, but is of less intensity. An interesting point with regard to the fasciculus cerebellospinalis is the fact that different fields of degeneration are revealed by the two methods at the highest levels of the cord. Concerning the descending degeneration, the most striking feature is that the degeneration in the dorsal funiculi extends but one segment below the lesion. In the lateral pyramidal tracts, the black dots representing degenerated fibres, can be followed as far down as the lumbar cord, but here they are only sparsely scattered. The degeneration is however well marked at this level in the Weigert preparations.

The fact that the oval field of Flechsig (the descending septo-marginal tract of Bruce and Muir‡) was not indicated by the Marchi specimen would go to indicate that this tract also degenerates rapidly. In fact, the recent cases of Hoche, Bruce and Muir, and Scarpatetti,* in which this tract and the comma of Schultze were thoroughly degenerated, were instances in which death ensued within a month or two after the onset of compression. Thus the individual fibres were caught in the first period of degeneration by the Marchi method, whereas they would not have been shown by other methods. By the Weigert method, these paths in the dorsal funiculi are shown only where the fibres are massed together and there has been considerable sclerosis, as found by Gombault and Philippe, who thus discovered their median triangle. In the present case there was some lightening of these areas in the Weigert preparations.

LEGENDS FOR FIGURES.

The lettering for the tracts is the same throughout. Each of the drawings of the spinal cord represents a magnification of five diameters.

F. cs. l.— Fasciculus cerebrospinalis lateralis (lateral pyramidal tract).
F. vl. G.—Fasciculus ventrolateralis superficialis (Gowersi).
F. cls.—Fasciculus cerebellospinalis.
F. c.— " cuneatus (Burdachi).
F. g.— " gracilis (Golli).
F. L.—Lissauer's fasciculus.
F. s.—Septal fasciculus.
Comma.—Schultze's comma fasciculus.
F. p. l.—Fasciculus proprius lateralis.

FIG. I. Level of the first cervical segment. Weigert-Pal preparation.

The degeneration of the tracts is indicated in this and the other Weigert preparations by a lightening in color.

FIG. II. Level of the first cervical segment. Marchi specimen.

FIG. III. Level of the second cervical segment. Weigert-Pal specimen.

FIG. IV. Level of the second cervical segment. Marchi specimen.

FIG. V. Level of the third cervical segment. Weigert-Pal specimen.

FIG VI. Level of the third cervical segment. Marchi specimen.

FIG. VII. Level of the fifth cervical segment. Weigert-Pal specimen.

FIG. VIII. Level of the seventh cervical segment. Weigert-Pal specimen.

FIG. IX. Level of the fourth thoracic segment. Weigert-Pal specimen.

FIG. X. Level of the fifth thoracic segment. Weigert-Pal specimen.

FIG. XI. Level of the sixth thoracic segment. Weigert-Pal preparation.

FIG. XII. Lumbar region of the cord. Weigert-Pal specimen.

FIG. XIII. Specimen from the region of compression. Stained by Van Gieson's method. Leitz objective $\frac{1}{12}$ (oil immersion), eye piece 3.

N.—Swollen irregular shaped nerve fibres, containing swollen deeply staining axones.

N.'—Nerve fibres containing vacuolic areas.

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*Schaffer, Karl. Beitrag zur Histologie der secundären Degeneration. Arch. f. mikr. Anat., Bonn, 1894, Bd. xliii, S. 252-266.

†Homén, E. A. Atlas d. path. Histol. d. Nervensyst., Berl., 1896, Lfg. vi, S. 5-19.

‡Bruce, A. and Muir R. On a Descending Degeneration in the Posterior Columns in the Lumbo-sacral Region of the Spinal Cord. Brain, Lond., 1896, vol. xix, pp. 333-345.

*Scarpatetti, J. von. Befund von Compression und Tuberkel im Rückenmark. Jahrb. f. Psychiat., Leipz. u. Wien, 1896-7, Bd. xv, S. 310-329.

FIG. I.

FIG. V.

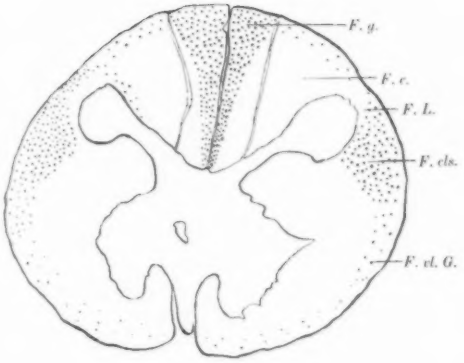

FIG. II.

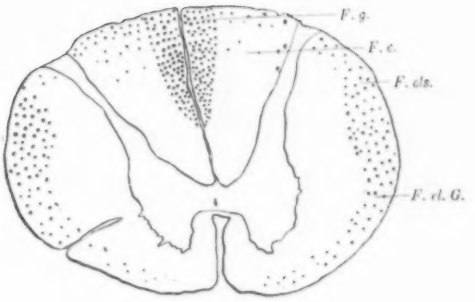

FIG. VI.

FIG. III.

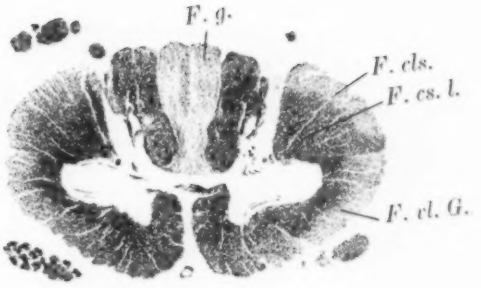

FIG. VII.

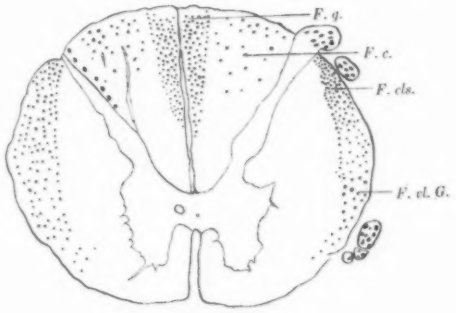

FIG. IV.

Schmidt and Rosenheim. del.

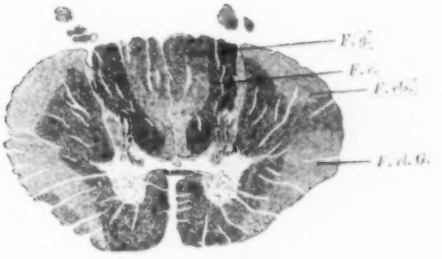

FIG. VIII

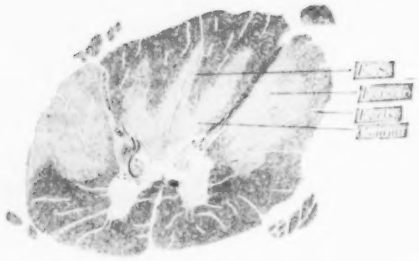

Fig. IX.

Fig. X.

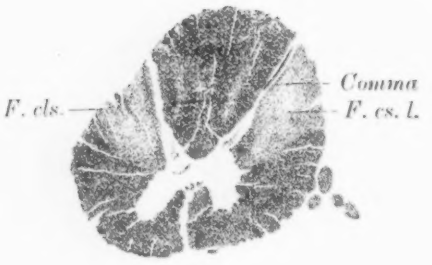

Fig. XI.

Fig. XII.

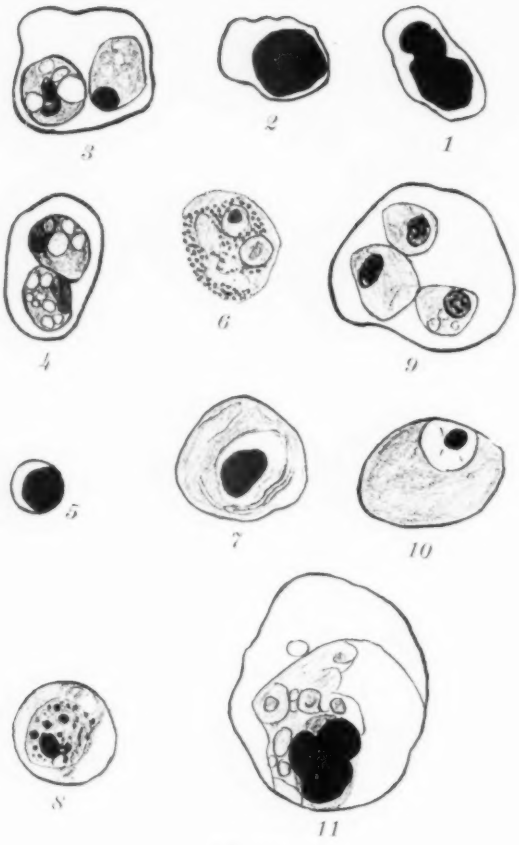

Fig. XIV.

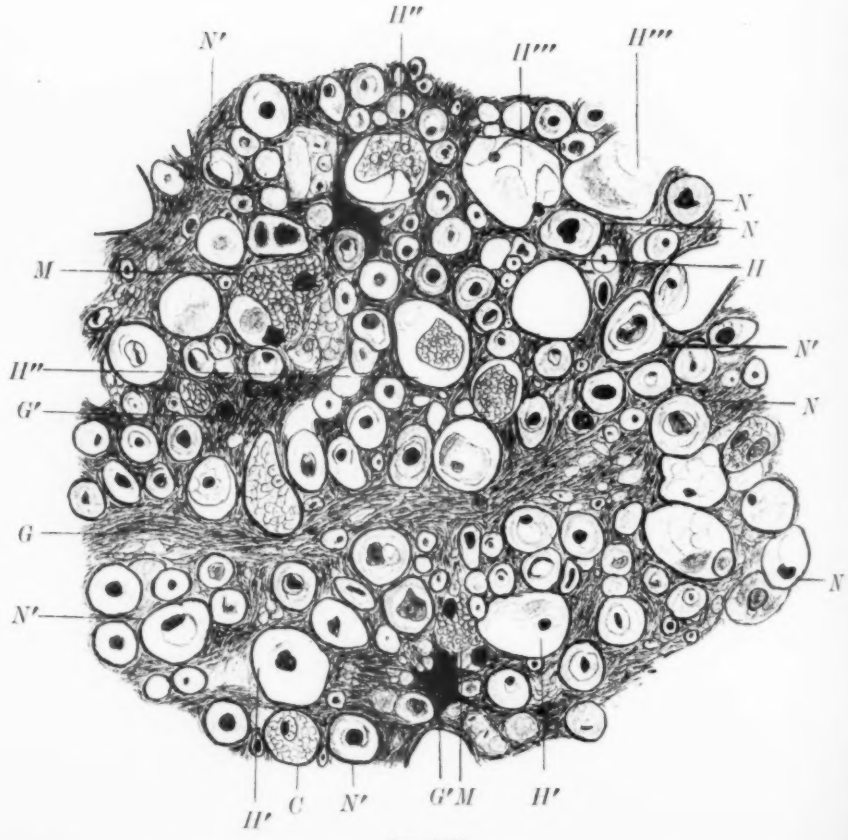

Fig. XIII.

Schmidt und Rauenheim, del.

G.—Neuroglia, greatly increased in amount.

G.' Nuclei of neuroglia cells.

M.—Masses of globular material imbedded in the neuroglia, staining a pinkish color.

H.—Empty hole.

H.'—Hole containing a disintegrating nerve fibre.

H.''—Holes containing masses of more or less globular appearance, staining a pinkish color. They are probably modified compound granular corpuscles.

H.'''—Holes containing material taking on a yellowish and pinkish coloration. Probably broken down nerve fibres.

C.—Compound granular corpuscle.

FIG. XIV. From various parts of the region of compression. Leitz objective $\frac{1}{12}$ (oil immersion), eye piece 3.

1 and 2. Corpora amylacea—Van Gieson's stains.

3 and 4. Eighth cervical segment. Two large irregular holes, containing cells, the nuclei of which stain a deep red color. The protoplasm contains vacuoles, and in parts looks as if it were made up of small globules. These are probably modified compound granular corpuscles Upson's carmine.

5. Second thoracic segment. Hole containing one of the corpora amylacea, which are very numerous at this level. It stains a pink color. Marchi's fluid and Upson's carmine.

6. Same section as 5. Shows several degenerating fibres. In one the axone stains a faint pink color; in another the axone is barely outlined. Numerous black globules of myelin are seen. The rest of the myelin has a faint yellowish color.

7. A nerve fibre is shown here, with a vacuolar area around the axis-cylinder.

8. Marchi specimen counter-stained in Upson's carmine. Hole containing a degenerating nerve fibre. The axone stains a fairly good pink color. The myelin sheath is represented partly by black granules, partly by a yellowish staining mass.

9. Haematoxylin and eosin. Hole containing three compound granular corpuscles. The nuclei stain black and are granular.

10. Eighth cervical segment. Van Gieson's stain. Swollen ganglion-cell. The protoplasm stains a homogeneous pink color. The nucleus is almost colorless; the nucleolus stains a deep pink color.

11. Weigert-Pal specimen counter-stained in Upson's carmine. Large hole containing several large black masses, surrounded by ball-like masses, which are outlined by darkly staining rings.

THE TREATMENT OF OTOMYCOSIS BY THE INSUFFLATION OF BORACIC ACID AND OXIDE OF ZINC.*

BY SAMUEL THEOBALD, M. D., *Clinical Professor of Ophthalmology and Otology, Johns Hopkins University.*

Seventeen years ago, in an article published in the American Journal of Otology,† I called attention to the value of a powder containing equal parts of boracic acid and oxide of zinc in the treatment of otomycosis aspergillina. In this article objection was urged to the use of alcohol, the agent most commonly employed for the destruction of aural fungi, on the ground that it not infrequently causes considerable pain when instilled into the auditory canal and tends to aggravate the inflammation of the canal walls and tympanic membrane usually present in otomycosis. A distinct gain, it was pointed out, would be made if a remedy could be found which would effectually destroy the parasite and at the same time exert a beneficial influence upon the inflammation excited by its presence; and such a remedy, it was claimed, had been found in the boracic acid and oxide of zinc powder.

Experiments were described which showed the specific action of boracic acid in destroying aspergillus and other fungi, and the drying effect of the oxide of zinc was held to render more effectual the germicidal action of the acid. At the same time, there was abundant evidence to show that the combination of the two, used as suggested (by insufflation), was one of the most efficacious remedies that we possess in overcoming diffuse inflammation of the external ear.

Although in the interval that has elapsed since the publication of this paper, I have used this remedy in all the cases of otomycosis that I have met with, and have never known it fail to destroy effectually the parasite—a single application often accomplishing this result, and more than two applications being seldom needed—I should not feel warranted in bringing the subject again to the attention of otologists but for the fact that the majority of them, to judge by the text-books, still seem to adhere to the practice, which, I think, should long since have become obsolete, of treating these cases by alcohol instillations.*

That alcohol is a suitable agent to pour into a diffusely inflamed and painful auditory canal will hardly be maintained by any one; while its relative inefficiency in destroying aspergillus seems to be shown by the statement of Politzer, that the instillations should be kept up for "a year" to prevent a return of the growth,† and that of Hovell, who says they should be repeated "two or three times a day" until the parasite is gotten rid of, and continued at intervals of a week for "several months" in order to guard against a relapse.‡ As opposed to this, we have the one, two or, at most, three applications of the zinc and boracic acid powder, at intervals of 24 or 48 hours, immediately and effectually eradicating the parasite, and at the same time, almost invariably, greatly benefiting the attendant inflammation.

The addition of bichloride of mercury or boracic acid to alcohol, as has been recommended, probably increases its parasiticidal effect, but certainly does not lessen its irritant action. Boracic acid and iodoform, mentioned among other agents by Gleason, ought to be efficacious, but, for the sake of our patients and their friends, iodoform should not be used if a less objectionable remedy will accomplish the same purpose. Chinoline salicylate and boracic acid, 1 part to 8 or 1 to 16, recommended by C. H. Burnett,§ is highly extolled by Robert Barclay.‖ I cannot speak of the value of this remedy from

* Read before the American Otological Society, July 18, 1898.

† Vol. III, No. 2, p. 119.

* Compare Politzer, Dench, McBride, Hovell, Gleason.

† Diseases of the Ear, p. 187.

‡ Diseases of the Ear and Naso-pharynx, p. 195.

§ Medical & Surg. Reporter, Phila., Vol. LXI, p. 539.

‖ Burnett's System of Diseases of the Ear, Nose and Throat.

personal experience, but I am prepared to believe that it must yield favorable results from the large proportion of boracic acid which it contains.

The boracic acid and oxide of zinc powder is open to the single objection that it is a somewhat insoluble compound, but this is not a serious objection, especially if it be blown into the ear, as it should be, only in sufficient quantity to cover lightly the walls of the meatus and the tympanic membrane. The parasite destroyed and the inflammation subdued, the removal of that portion of the powder which may have adhered to the membrane and canal walls may be safely left to nature, which, through the outgrowth of the epidermis, will accomplish this completely within the course of a few weeks.

A brief description of a single typical case, recently under observation, will suffice to illustrate the action of this remedy and the manner of its employment.

Mr. X, of Baltimore, consulted me in the latter part of May last, because of an uncomfortable "full feeling," attended by slight pain, in the left ear. The history of the case indicated that there had been a slight dermatitis in each auditory canal for a considerable time. The symptoms complained of in the left ear were found to be due to the presence of aspergillus nigricans, which had excited a well-marked diffuse inflammation of the deeper portion of the canal walls and the tympanic membrane.

By the aid of the syringe, probe and forceps the aspergillus was removed as completely as possible and the meatus was freed of a considerable quantity of exfoliated epithelium. The ear was then dried and the boracic acid and zinc powder blown in lightly. On the following day, although the unpleasant symptoms were entirely relieved, the treatment was repeated as a matter of precaution. This completed the cure, which a lapse of three weeks has shown to be radical.

BOOKS RECEIVED.

Atlas and Abstract of the Diseases of the Larynx. By Dr. L. Grünwald, of Munich. Authorized Translation from the German. Edited by Charles P. Grayson, M. D. 1898. 12mo. With 107 Colored Figures on 44 Plates. 103 pages. W. B. Saunders, Philadelphia.

On Cardiac Failure and its Treatment, with Especial Reference to the Use of Baths and Exercises. By Alexander Morison, M. D., F. R. C. P 1897. 8vo, 256 pages. The Rebman Publishing Co., London.

Hay Fever and its Successful Treatment. By W. C. Hollopeter, A. M., M. D. 1898. 12mo, 137 pages. P. Blakiston's Son & Co., Philadelphia.

A Report on Vaccination and its Results, Based on the Evidence Taken by the Royal Commission during the Years 1889–1897. Vol. I. The Text of the Commission Report. 1898. 8vo, 493 pages. New Sydenham Society, London.

A Text-Book upon the Pathogenic Bacteria. For students of medicine, and physicians. By Joseph McFarland, M. D. Second edition, revised and enlarged. 1898. 8vo, 497 pp. W. B. Saunders, Phila.

An American Text-Book of the Diseases of Children. By American teachers. Edited by Louis Starr, M. D., assisted by T. S. Westcott, M. D. Second edition, revised. 1898. 4to, 1244 pp. W. B. Saunders, Philadelphia.

The Diseases of the Stomach. By William W. Van Valzah, A. M., M. D., and J. Douglas Nisbet, A. B., M. D. 1898. 8vo, 674 pp. W. B. Saunders, Philadelphia.

Twelfth Annual Report of the State Board of Health of the State of Ohio, for the year ending October 31, 1897. 8vo, 308 pp. 1898. The Laning Printing Co., Norwalk, Ohio.

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Second Catalogue of the Library of the Peabody Institute of the City of Baltimore, including the additions made since 1882. Part III, E-G. 1898. 4to, 2006 pp. Baltimore.

An American Text-Book of Gynecology, Medical and Surgical, for practitioners and students. By H. T. Byford, M. D., *et al.* Edited by J. M. Baldy, M. D. Second edition, revised. 1898. 4to, 718 pp. W. B. Saunders, Philadelphia.

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King's College Hospital Reports; being the annual report of King's College and the medical department of King's College. Edited by N. Tirard, M. D., F. R. C. P., *et al.* Vol. IV. (Oct. 1st, 1896–Sept. 30th, 1897). 1898. 8vo, 358 pp. Adlard and Son, London.

The Office Treatment of Hemorrhoids, Fistula, etc., without operation. By Charles B. Kelsey, A. M., M. D. 1898. 12mo, 68 pp. E. R. Pelton, New York.

Twentieth Century Practice. An International encyclopedia of modern medical science by leading authorities of Europe and America. Ed. by Thos. L. Stedman, M. D. Vol. XV. Infectious Diseases. 1898. 8vo, 658 pp. Wm. Wood & Co., New York.

The Principles and Practice of Medicine. By William Osler, M. D. Third Edition. 1898. 8vo, 1181 pp. D. Appleton & Co., New York.

The Mineral Waters and Health Resorts of Europe. Treatment of chronic diseases by spas and climates with hints as to the simultaneous employment of various physical and dietetic methods. Being a revised and enlarged edition of "The spas and mineral waters of Europe." By H. Weber, M. D., F. R. C. P., and F. P. Weber, M. D., F. R. C. P. 1898. 8vo, 524 pp. Smith, Elder & Co., London.

A Clinical Text-Book of Medical Diagnosis for Physicians and Students. By Oswald Vierordt, M. D. Authorized translation with additions by F. H. Stuart, A. M., M. D. Fourth American edition, from the fifth German, revised and enlarged. 1898. 8vo, 603 pp. W. B. Saunders, Philadelphia.

WALTER S. DAVIS, M. D.

At a meeting held at 4.30 o'clock Wednesday afternoon, on the twenty-eighth of September, in the office of the superintendent of Johns Hopkins Hospital, presided over by Dr. H. M. Hurd, the following resolutions were adopted:

Whereas, we have lost our beloved comrade and fellow-worker, WALTER S. DAVIS;

Be it Resolved, That we, the Medical Faculty of the Johns Hopkins University and the staff of the Johns Hopkins Hospital do express to his family our most heartfelt sympathy in their great bereavement.

His enthusiasm in the profession was unbounded and always a stimulus to his co-workers; but we shall remember him particularly for his sterling character, his ever cheerful disposition, and his fidelity as a friend, and,

Be it further Resolved, That a copy of these resolutions be conveyed to his family and published in the Bulletin of the Johns Hopkins Hospital.

THOMAS S. CULLEN,
JAMES F. MITCHELL,
GUY L. HUNNER.
Committee.

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